Global Status of Transgenic Crops in 1997

Clive James
Chair, ISAAA Board of Directors

Table 6: Global Area of Transgenic Crops in 1996 and 1997
(millions of hectares/acres)

	Hectares (million)	**Acres** (million)
1996	2.8	7.0
1997	12.8	31.5

Increase in acreage from 1996 to 1997 is 4.5 fold.

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Transgenic Field Trials 1986-1997

During the twelve year period 1986 to 1997, approximately 25,000 transgenic crop field trials were conducted globally on more than 60 crops with 10 traits in 45 countries. Of this total of 25,000, 15,000 field trials (60 percent) were conducted during the first ten year period, 1986 to 1995, and 10,000 (40 percent) in the last two year period, 1996-1997. Seventy-two percent of all the transgenic crop field trials were conducted in the USA and Canada followed in descending order by Europe, Latin America and Asia, with the few conducted in Africa limited to South Africa. The most frequent crops featured in transgenic crop field trials during the period were corn, tomato, soybean, canola, potato, and cotton and the most frequent traits were herbicide tolerance, insect resistance, product quality and virus resistance. It is noteworthy that 25,000 transgenic crop trials were conducted without encountering any significant constraints that did not lend themselves for successful and responsible management during experimentation at the field level. This reflects well on regulators and experimenters who worked together effectively to conduct and manage 25,000 trials in a responsible manner and ensured that the results were communicated in a transparent mode and open for scrutiny and discussion by the scientific community and the lay public. The continued sharing of information from transgenic crop trials and their performance during commercial deployment is important and will contribute to a better understanding of transgenic crops and enhance public acceptance of products that can make a critical contribution to future global food security. As of year-end 1997, 48 transgenic crop products, involving 12 crops and 6 traits, were approved for commercialization in at least one country by 22 proprietors of technology, of which 20 were private sector corporations.

1996 Commercialized Transgenic Crops

The People's Republic of China was the first country to commercialize transgenics in the early 1990s with the introduction of virus resistant tobacco, which was later followed by a virus resistant tomato. In 1994, Calgene obtained the first approval in the USA to commercialize a genetically modified food product, when the company marketed its Flavr Savr ™ delayed ripening tomato. By 1996, approximately 7 million acres (2.8 million hectares) of 7 principal transgenic crops were grown commercially on a significant area in the following 6 countries, listed in descending order of acreage: USA, China, Canada, Argentina, Australia and Mexico. In 1996, on a global basis, 57 percent of the transgenic crop area was grown in the industrial countries and 43 percent in the developing countries. USA grew most of the transgenic crop, equivalent to 3.6 million acres or 1.5 million hectares (51 percent), followed by China, 2.8 million acres or 1.1 million hectares (39 percent), with Canada and Argentina at the same level of 0.3 million acres or 0.1 million hectares (4 percent), and the balance in Australia (1 percent) and Mexico (1 percent). In 1996, the principal transgenic crop was tobacco which accounted for 35 percent (equivalent to 2.5 million acres or 1.0 million hectares) of the global area, followed by cotton (27 percent) on 1.9 million acres or 0.8 million hectares, and soybean 18 percent (1.25 million acres or 0.5 million hectares); the balance of 20 percent was made up of corn (10 percent), canola (5 percent), tomato (4 percent), with less than 1 percent of global transgenic area occupied by potatoes. By trait, virus resistance accounted for 40 percent of the transgenic acreage in 1996, followed by insect resistance - synonymous with insect-protected (37 percent), herbicide tolerance (23 percent), with quality traits accounting for less than 1 percent.

1997 Commercialized Transgenic Crops

In 1997, the global area of transgenics increased 4.5 fold from 7.0 million acres (2.8 million hectares) in 1996 to 31.5 million acres (12.8 million hectares) with 7 crops grown in 6 countries, as in 1996, with 48 transgenic crop products approved in at least one country. The countries listed in descending order of transgenic crop area were: USA, 20.1 million acres or 8.1 million hectares representing 64 percent of the global acreage, China with 4.5 million acres or 1.8 million hectares equivalent to 14 percent, Argentina with 3.5 million acres or 1.4 million hectares representing 11 percent of global acreage, Canada with 3.0 million acres or 1.3 million hectares representing 10 percent of global area and Australia (0.1million acres or <0.05 million hectares) and Mexico, <0.1 million acres or 0.03 million hectares, both representing less than 1 percent of the global transgenic crop area. On a global basis, the proportion of transgenic acreage grown in industrial countries increased from 57 percent in 1996 to 75 percent in 1997, and it decreased in developing countries from 43 percent in 1996 to 25 percent in 1997. The largest increase in transgenic crops in 1997 occurred in the USA (16.5 million acres or 6.7 million hectares) where the increase was more than fivefold (5.6) followed by Argentina (3.25 million acres or 1.3 million hectares) where there was a 13 fold increase, and Canada with an increase of 3.0 million acres or 1.3 million hectares, representing a 9.2 fold increase. USA continued to be the principal grower of transgenic crops in 1997 and its share of global acreage increased from 51 percent in 1996 to 64 percent in 1997, equivalent to 20.1 million acres or 8.1 million hectares. Whereas China, in 1997, still retained its 1996 ranking as the country with the second largest area, its percentage of global transgenic crop acreage decreased sharply from 39 percent in 1996 to 14 percent in 1997. Argentina's transgenic crop acreage increased from 4 percent of global area in 1996 to 11 percent in 1997 and similarly in Canada from 4 percent to 10 percent. There were also significant changes in the absolute and relative area occupied by the 7 transgenic crops in 1996 and 1997. Transgenic soybean ranked first in 1997, accounting for 40 percent of global acreage, and replaced tobacco (13 percent in1997) which was the highest ranking crop in 1996 with 35 percent of the global area. Corn, which only ranked fourth in 1996 (10 percent of global area) moved up to second position in 1997 with 7.9 million acres or 3.2 million hectares, equivalent to 25 percent of the global transgenic area. The proportion of global acreage occupied by transgenic canola increased from 5 percent in 1996 to 10 percent in 1997, whereas the area of cotton decreased from 27 percent to 11 percent and similarly tomato from 4 percent to 1 percent. The relative areas occupied by the four transgenic traits were also significantly different in 1996 and 1997. Herbicide tolerance, the third ranking trait in 1996 and occupying 23 percent of the area, moved to the top ranking position in 1997 with 54 percent of the global area. Insect resistance was fairly stable with 37 percent in 1996 and 31 percent in 1997, with virus resistance decreasing sharply from 40 percent in 1996 to 14 percent in 1997; quality traits occupied less than 1 percent in both 1996 and 1997.

Major Changes 1996 to 1997

Considering the global share of transgenics for the respective countries, crops and traits, the major changes between 1996 and 1997 were correlated with the following features: growth in area of transgenics between 1996 and 1997 in the industrial countries was significant and almost 4 times greater than in developing countries (19.5 million acres versus 5.0 million acres, or 7.9 million hectares versus 2.0 million hectares); soybean and corn contributed 75 percent of the global growth in transgenics between 1996 and 1997; herbicide tolerance was responsible for 63 percent (15.4 million acres or 6.2 million hectares) of the global growth in transgenics between 1996 and 1997, with insect resistance contributing 30 percent and virus resistance only 7 percent. The principal phenomena that influenced the change in absolute area of transgenic crops between 1996 and 1997 and the relative global share of different countries, crops and traits were: firstly, the enormous increase in 1997 of herbicide tolerant soybean in the USA and to a lesser extent in Argentina; secondly, the significant increase in 1997 of insect resistant corn in North America; and thirdly, the large increase of herbicide tolerant canola in Canada in 1997. Collectively, these three phenomena resulted in a global acreage in 1997 that was 4.5 times higher than 1996, and the relative importance of transgenic tobacco and tomato in China, which was significant in 1996, decreased markedly in 1997 in a global context. In 1997, transgenic soybean, corn, cotton and canola represented 86 percent of the global transgenic area, of which 75 percent was grown in North America with herbicide tolerant soybean being the most dominant transgenic crop followed by insect resistant corn and herbicide tolerant canola.

Estimated Benefits from Transgenic Crops

More detailed information on the benefits associated with new transgenic crops will be available following a comprehensive analysis of 1997 data, when a substantial acreage of transgenics was planted globally. An initial assessment of the benefits from transgenic crops is reported here: virus resistant tobacco in China increased leaf yield by 5 to 7 percent and resulted in savings of 2 to 3 insecticide applications; insect resistant *Bt* cotton in the USA in 1996 resulted in insecticide savings, with 70 percent of *Bt* cotton planted in 1996 requiring no insecticides to control the targeted insect pests, and an average yield increase of 7 percent - this resulted in a net benefit of $ 33 per acre for a total national benefit of $ 60 million for the 1.8 million acres (730,000 hectares) of *Bt* cotton in the USA in 1996; borer-resistant *Bt* corn in USA produced an average yield increase of 9 percent in 1996 and 1997 - benefits from the use of *Bt* corn on 700,000 acres (285,000 hectares) in the USA in 1996 were estimated at $ 19 million and $ 190 million for the 7 million acres (2.8 million hectares) of *Bt* corn planted in 1997 - 50 percent of the 80 million corn acreage in the USA, equivalent to 40 million acres (16 million hectares) was reported to be infested with European corn borer, with an estimated annual loss of $ 1 billion; herbicide tolerant soybean in USA in 1996 resulted in 10 to 40 percent less herbicide requirements, improved yield dependability, no carry-over of herbicide residues, more flexibility in agronomic management and better control of weeds and soil moisture conservation; herbicide tolerant canola in Canada in 1996 lowered herbicide requirements, increased yield by an average of 9 percent, with no carry-over of herbicide residues, more flexibility in agronomic management, plus a higher proportion of #1 Grade canola, 85 percent versus 63 percent, as well as better soil and moisture conservation - benefits to Canada from the use of 300,000 acres of herbicide tolerant canola in 1996 were estimated to be $6 million; insect resistant *Bt* potatoes in USA in 1996 resulted in effective control of Colorado beetle, yield/quality benefits per acre of $ 14 and insecticide savings of $ 5, for a net benefit of $ 19 per acre that translated to a total benefit of $170,000 for the 9,000 acres (3,650 hectares) of *Bt* potatoes in the USA in 1996. Thus, at a national level in the USA in 1996, the total benefits for *Bt* cotton, corn and potato were $ 80 million, and $ 190 million for *Bt* corn alone in 1997; similarly at the national level the benefits from herbicide tolerant canola in Canada in 1996 were $ 6 million. In general, transgenic crops have been well received in North America, with a very high percentage of farmers who planted transgenic crops in 1996 electing to plant again in 1997; many transgenic products were unavailable to potential growers in North America in 1997 because of shortage of transgenic seed supplies, thus reducing the potential area planted to transgenic crops.

The Future - Biotechnology Investments and Global Markets

Global sales for agricultural biotechnology will continue to be modest compared with biotechnology-based pharmaceutical products. In the USA in 1995 revenues from agricultural biotechnology were estimated at $ 0.100 billion with R&D costs of $2 billion, whereas revenue for biotechnology-based pharmaceuticals was $ 7 billion with R&D costs of $ 8 billion; in 1996 revenues for agricultural biotechnology products in the USA increased to $ 304 million and to $ 8.6 billion for biotechnology-based pharmaceuticals. However, revenue from agri-biotech products is expected to increase significantly in the future as expansion of transgenic crops continues and as a shift occurs 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; the recent $ 1.7 billion joint venture between DuPont and Pioneer is probably directed at this market. Biotechnology-driven acquisitions, mergers and alliances will continue to prevail in the seed and pesticide industry which has invested $ 8 billion in acquisitions in agri-biotechnology alone in the last few years, although the thrust in the future will change to vertical integration of food, feed and industrial products, and the current focus on genomics will catalyze new alliances. The future for transgenic crops looks promising, with crop areas in North America likely to increase significantly in 1998, deeper market penetration in Latin America and Australia, new products in China and the advent of commercial transgenic crops in Europe. The global market for transgenic crops is projected to increase from $ <0.5 billion in 1996, to $ 2 to $ 3 billion in 2000, to $ 6 billion in 2005, and to $ 20 billion in 2010. During the next decade an increase in productivity of 10 to 25 percent from transgenic crops is feasible and realistic and this will be a critical and significant contribution to global food security, more nutritious food and feed, and to a safer environment.

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Introduction

Of today's world population of 5.8 billion people, it is estimated that over 800 million people do not have adequate food, and 1.3 billion people live on less than $1 of income per day. Approximately fifty percent of the world's poor people live in Asia, twenty five percent in Africa, twelve percent in Latin America and the balance in other areas of the world (IRRI 1996). The majority of these poor people live in rural areas of developing countries where the land is marginal and the ecosystems fragile. Currently, 80 percent of the global population reside in the developing world, where the annual increase in population is 1.9 percent. The pertinent statistics on world population and the respective growth rates for developing and industrial countries are summarized for convenience in Table 1. It is now widely acknowledged that conventional technology alone will not allow food, feed and fiber production to be increased sufficiently to meet the needs of the 10 billion global population of the 21st century. Whereas crop productivity is still increasing, the annual rate of growth is declining; world grain yields grew at an annual rate of 2.1 percent during the 1980s but fell to less than 1.0 percent in the 1990s (Kendall et al 1997). Abiotic stresses and non-sustainable agricultural practices have led to decreased productivity of agricultural land; this has been due to several factors including wind and water erosion, salinization, overgrazing and overintensification. For example, erosion alone leads to the irreversible loss of 23 billion tons of top soil per year (equivalent to 0.7 percent per annum) that will result in 20 to 25 percent loss of top soil by the year 2025 (Norse *et al* 1992); an additional 0.7 percent is lost annually to degradation and urbanization. Erosion alone has rendered unusable 1 billion hectares of cultivable land (FAO 1993). On a global basis the amount of cultivable land has decreased from 0.44 ha. per capita in 1961 to 0.26 ha. in 1997 and is expected to fall further to 0.15 ha. per capita by the year 2050 (Engelman and LeRoy 1995). Given that the rate of expansion of arable land is now below 0.2 percent per annum and continuing to fall, increasing productivity, through increasing production per unit area of land, represents the only significant means for increasing food, feed and fiber production. Equally important, is recognition of the need to evolve and practice a sustainable system of agriculture that will increase productivity, conserve natural resources, and protect the environment.

Table 1: World Population and Growth Rates 1997

Industrial and Developing Countries

Population	Millions	Growth Rate
Developing Countries	4,600	1.9
Industrial Countries	1,200	0.1
Global	5,800	1.5

Selected Information for Developing Countries

Population	Millions	Growth Rate
China	1,200	1.1
India	950	1.9
Least Developed	560	2.8

Note: 87 million people added to global population annually.
Source: Kendall *et al.* 1997.

Research and development (R&D) in biotechnology, including development, field testing and commercialization of transgenic crops, is now recognized by the international scientific community to be an essential, and increasingly important element of a critical strategy integrating both conventional and biotechnology applications in order to achieve future global food security. Acknowledging that the private sector is the major investor in biotechnology, progressing public-private sector partnerships in agricultural research and development to maximize access to the new technologies and to optimize limited and inadequate global R&D agricultural resources in both the industrial and developing countries is also considered important (James 1996 and 1997). The testing of transgenic crops is regulated by governments in both industrialized and developing countries because of the need to safeguard the environment and the fact that transgenics represent new products that, until recently, were unfamiliar to the scientific community and the lay public. The first field trials of transgenic crops were conducted in 1986 in the United States and France, and featured herbicide tolerance, as a marker gene in tobacco. In the decade 1986 to 1995 more than 3,500 field trials of transgenic crops were conducted on more than 15,000 individual sites in 34 countries with at least 56 crops, mostly in North America and Europe (James and Krattiger 1996). Ninety-one percent of these trials were conducted in industrialized countries, and one percent in Eastern Europe and Russia; the balance of eight percent were conducted in developing countries, mostly in Latin America, with only two percent of trials conducted in the developing countries of Asia, almost exclusively in the Peoples Republic of China. The majority of the transgenic crop field trials in the period 1986 to 1995 were conducted in the

United States, Canada, France, United Kingdom, the Netherlands, Belgium, Argentina, Italy, China, Germany, Australia, Chile and Mexico, listed in decreasing order of the number of trials conducted. Thus, the process of testing and developing appropriate legislation has taken more than a decade to develop and implement prior to the commercial adoption of transgenic crops which is now underway in several countries.

China was the first country to commercialize transgenics in the early 1990s with the introduction of virus resistant tobacco, and later a virus resistant tomato. The first approval for commercial sale of a genetically modified product for food use in an industrialized country was in the United States in May 1994 when Calgene marketed its Flavr-Savr™ delayed ripening tomato. By year-end 1995, 35 applications or petitions had been granted to commercially grow 9 transgenic crops, with most approvals in the United States and Canada, which together accounted for 80 percent of the number of approvals worldwide. By 1996, on a global basis, approximately 7 million acres (2.8 million ha.) of 7 principal transgenic crops were grown commercially on 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 The two major growers of transgenic crops were the United States and China, and the principal crops were tobacco, followed by cotton and soybean; virus resistance was the major trait followed by insect resistance and herbicide tolerance. To-date, transgenic crops have established a credible record and the development and implementation of appropriate biosafety regulations has served an important function. A consequence of employing appropriate biosafety guidelines is that the management of biotechnology, since its genesis 25 years ago, has increasingly gained the confidence of scientists, regulators, policy makers, politicians and the lay public. 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 China, Argentina and Mexico, whilst progress is evident but slower in the countries of the European Union (Hoban 1997).

The principal aim of this publication is:

- to present a global overview of transgenic crop field tests through year-end 1997;
- to review the transgenic crops currently approved for commercialization;
- to document detailed information on the global status and distribution of commercial transgenic crops in 1996 and 1997 by region, country, crop and trait;
- to provide an initial assessment of the benefits resulting from the use of transgenic crops grown commercially in 1996; and finally
- to comment on future developments that will affect the growth and commercialization of transgenic crops in the near-term and in the first decade of the 21st century.

Overview of Global Transgenic Crop Field Trials, 1986-1997

Number of Countries, Crops and Traits

During the first decade of transgenic field trials, 1986 to 1995, James & Krattiger (1996) reported that 3,647 permits for field trials had been issued to conduct experiments on more than 15,000 individual sites with at least 56 crops and 6 groups of traits in 34 countries. More recent reports show that since 1995 additional countries have initiated transgenic field trials; these include India, Malaysia, Czech Republic, Georgia, Poland, Rumania, Slovakia, Turkey, Ukraine, Yugoslavia and possibly Uzbekistan. There may well be other countries in addition to the 45 countries listed in Table 2 that have conducted trials but have not yet reported their implementation. It is noteworthy that India initiated transgenic crop field trials in 1997 with *Bt* cotton and herbicide tolerant Indian mustard; Malaysia with transgenic rubber and Turkey with several crops including potatoes and cotton with *Bt.* Since 1996 considerable progress has been made in various countries of Eastern Europe, including Turkey, Russian Federation, Czech Republic, Hungary, Rumania, Poland, Ukraine and Slovakia. The field trials prior to 1996 in Eastern European countries mainly featured virus resistance in various crops with some work on insect resistance followed by herbicide tolerance. However, the trials from 1996 onwards have concentrated more on herbicide tolerance of various crops including sugar beet, oilseed rape/canola, corn, cotton and soybean, and insect resistant corn and potatoes, in addition to continued work on virus resistance in various crops. Commercialization of the first transgenic crops are expected as early as 1998 in Turkey and possibly Ukraine.

James and Krattiger (1996) list 56 transgenic crops that were tested in field trials until the end of 1995; by 1997 this list increased to 60 (see Appendix Table 1A). The new crops include Brown and Indian Mustard, Blueberry and Broccoli. During 1996 and 1997 significant progress has been made with the globally important staple wheat crop, which until recently posed considerable challenges in terms of routine commercial transformation of the major cultivars grown in the industrial and developing countries of the world.

Data in Table 3 provide an overview of the progress in conducting transgenic crop field trials during the first decade (1986 to 1995) and the following two year period, 1996 and 1997. Approximately 15,000 field trials were conducted at individual locations in 34 countries during the ten years 1986 - 1995, and in 1996 and 1997 the number of countries conducting trials increased to 45 with an additional 10,000 individual trials conducted in only two years. Stated another way, of the total number of transgenic crop trials conducted to date, 40 percent have been conducted in only the last two years, as compared with 60 percent during the first ten year period 1986 to 1995. Thus, the number of trials has increased annually from 1986 to 1997, with substantial annual increases from 1992 onwards. For example, in the United States, the number of field sites increased from 81 in 1990 to 381 in 1992, to 1,926 in 1994, to 2,998 in 1996 (Payne 1997). During the last two years The Animal and Plant Health and Inspection Service (APHIS) of the United States Department of Agriculture (USDA) has considered requests for determining that particular field tested transgenic products have no potential for plant pest risk and should no longer be regulated. These requests from the developers of new products, produced through biotechnology, facilitate the entry of the products into the market place. As of September 1997, the following twelve new products were determined by APHIS (APHIS 1997) to be no longer subject to regulation:

1. Insect-resistant corn, Northrup King Co., January 1996.
2. Herbicide-tolerant cotton, DuPont Agricultural Products, January 1996.
3. Male-sterile corn, Plant Genetic Systems (America), Inc. February 1996.

Table 2: 45 Countries that have Conducted Transgenic Crop Field Trials from 1986 to 1997

Argentina Australia Belgium Belize Bolivia Bulgaria Canada Chile China Costa Rica Cuba Czech Republic	Denmark Egypt Finland France Georgia Germany Guatemala Hungary India Italy Japan	Malaysia Mexico New Zealand Norway Rumania Russia Poland Portugal Slovakia Spain South Africa	Sweden Switzerland Thailand The Netherlands Turkey Ukraine United Kingdom USA Uzbekistan* Yugoslavia Zimbabwe

*Reported; reconfirmation in process
Source: Clive James.

Table 3: Global, USA, and Canada Transgenic Crop Field Trials, 1986-1995, and 1996 to 1997

Period	# of Crops	# of Countries	# of Trait Groups	Global	# of Field Trials USA	Canada
1986 to 1995	56	34	6	15,000	7,368	2,312
1996 to 1997	60	45	10	10,000	6,785	1,435
1986 to 1997	60	45	10	25,000	14,153	3,747

Source: Data provided from APHIS/USDA by John Payne (1997) and Canadian Food Inspection Agency by Stacey Charlton (1997). Compiled by Clive James.

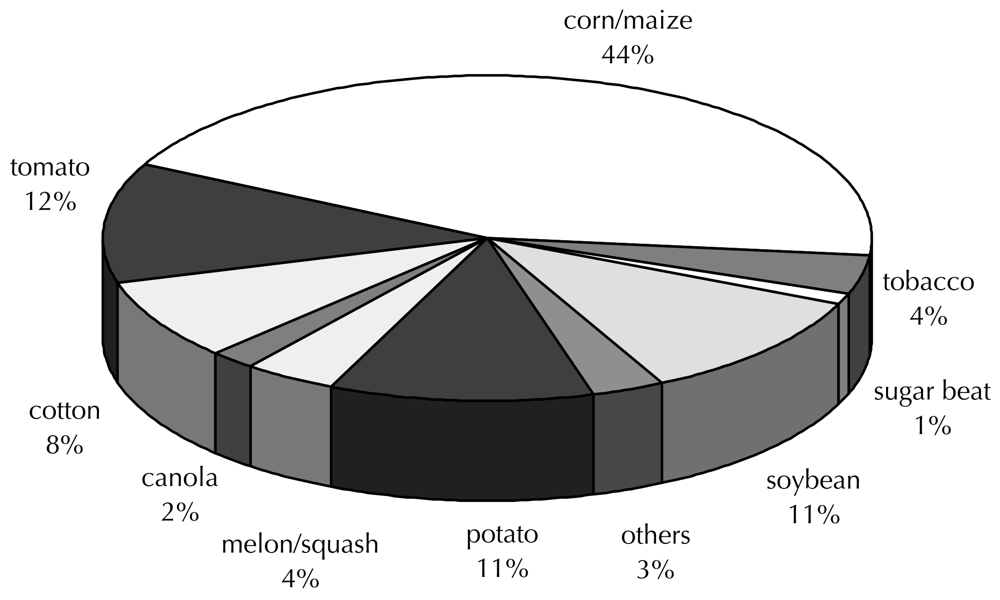
4. Altered-ripening tomato, Agritope, Inc., March 1996.
5. Colorado potato-beetle-resistant-potato, Monsanto Co., May 1996.
6. Virus-resistant squash, Asgrow Seeds, June 1996.
7. Herbicide-tolerant soybean, AgrEvo, July 1996.
8. Virus-resistant papaya, Cornell University and The University of Hawaii, September 1996.
9. Insect-resistant corn, DeKalb Genetics Corp., March 1997.
10. Insect-resistant cotton, Calgene, Inc., April 1997.
11. High oleic acid soybean, DuPont Agricultural Products, May 1997.
12. Insect-resistant corn, Monsanto Co., May 1997.

During the period 1986 to 1997 approximately 57 percent of global trials were conducted in the United States and 15 percent in Canada, which together represent approximately 72 percent of total trials conducted globally (Table 3); thus of the 25,000 trials conducted to date approximately 17,900 were conducted in the United States and Canada,. However this significant increase in the number of trials conducted during 1996 and 1997 was not restricted to the United States and Canada because many other countries that initiated early transgenic crop field trials experienced the same significant increases in number of field trials in 1996 and 1997. For example, Mexico conducted an average of only 4 to 5 transgenic crop field trials during the period 1987 to 1995 whereas the number increased significantly to 25 to 30 per year in 1996 and 1997 (Sanidad Vegetal 1997).

Most Frequent Crops and Traits in the USA

Figures 1 and 2 show the relative frequency of crops and traits in transgenic field trials conducted in the United States during the period 1987 to 1997. From a crop perspective (Figure 1), corn is by far the most frequent at 44 percent. tomato, soybean and potato, each represent from 10 to 15 percent of trials, cotton at 8 percent, and the balance of four crops that include melon/squash, tobacco, canola and sugar beet as well as other crops representing less than 5 percent each. The corresponding global distribution of transgenic crops represented in field trials would not differ too much from the US data in Figure 1 except that corn would be slightly lower and canola, potato, cotton and sugar beet slightly higher. Figure 2 shows that the three most frequent traits in the USA in the period 1987 to 1997 represented 80 percent of all traits; these were herbicide - tolerance, 30 percent, followed by insect resistance at 24 percent, and product quality at 21 percent, with viral resistance accounting for 10 percent, fungal resistance 4 percent, agronomic properties 4 percent and the balance of 7 percent collectively by other traits. The corresponding

Figure 1: Number of Transgenic Crop Field Trial Sites in the USA, 1987 to 1997: Most Frequent Crops
(expressed as percentage)



global distribution for traits does not differ significantly from the US distribution depicted in Figure 2.

Most Frequent Crops and Traits in Canada

Table 4 indicates the trends in transgenic crop field trials in Canada by crop and by trait during the period 1990 to 1997 when there was more than a tenfold increase in the annual number of trials, from 78 trials in 1990 to 499 in 1995, up to a high of 823 in 1997. In 1990 the range of crops was narrow with Canola napus representing 78 percent of field trials, potatoes 4 percent, corn 3 percent, alfalfa 3 percent, with the balance of 12 percent, made up of crops such as tobacco (which served as a model crop), tomato and flax. From 1990 to 1995 the transgenic crop range broadened to a more balanced portfolio that included Canola rapa, soybean, and wheat, and by 1997 more equilibrium between crops was achieved with Canola napus occupying only 39 percent of the trials as compared with 78 percent in 1990. Similarly potato trials increased from 4 to 19 percent, and wheat from 0 to 2 percent respectively between 1990 and 1997. A similar trend is observed with traits in Table 4, where herbicide tolerance represented 90 percent of trials in Canada in 1990, decreasing to 74 percent in 1995, and to 52 percent in 1997, whilst the number of traits increased from five in 1990 to eight in 1997. Trials featuring insect, virus, and fungal resistance increased between 1990 and 1997; modified oil, nutrition and stress tolerance have featured from the outset and are likely to increase in importance in the future, as output traits become more dominant in relation to input traits that are currently the most prevalent. In Canada in 1990, 81 percent of all transgenic crops were transformed with *Agrobacterium*, decreasing to 70 percent in 1995 and 67 percent in 1997. On the contrary, during the same period transformation by bolistics increased from 3 percent in 1990 to 10 percent in 1995, and remains at 10 percent in 1997.

Summary

In summary, during the twelve year period 1986 to 1997, approximately 25,000 field trials were conducted on more than 60 crops with 10 traits in 45 countries. In the 1990s, there was an explosive growth in the number of trials globally which is depicted in Figure 3 with a total of 15,000 conducted in the first decade that terminated in 1995 and increasing by a significant number of 10,000 in only two years in 1996 and 1997, to reach a total of 25,000 by the end of 1997. Thus, of the total number of transgenic crop field trials conducted to-date, 40 percent were conducted in 1996 and 1997 as compared with only 60 percent during the first ten period of transgenic crop field trials during the period 1986 to 1995. Approximately seventy percent of all transgenic crop field trials conducted during the period 1986 to1997 were completed in the USA and Canada, followed in descending order by Europe, Latin America and Asia with the few conducted in Africa limited to South Africa. The most frequent crops featured in transgenic crop field trials during the period 1986 to 1997 were corn, tomato, soybean, canola, potato, and cotton and the most frequent traits were herbicide tolerance, insect resistance, product quality and virus resistance. It is noteworthy that the 25,000 transgenic crop trials conducted during the period 1986 to1997 have been conducted without encountering any significant constraints that did not lend themselves for successful and responsible management during experimentation at the field level. This reflects well on the regulators and experimenters who have worked together effectively to conduct and manage the 25,000 trials in a responsible manner and ensured that the results are communicated in a transparent mode and are open for scrutiny and discussion by the scientific community and the lay public. The continued sharing of information from transgenic crop trials and their performance during commercial deployment is important and will contribute to a better understanding of transgenic crops and enhance public acceptance of products that can make a critical contribution to future global food security.

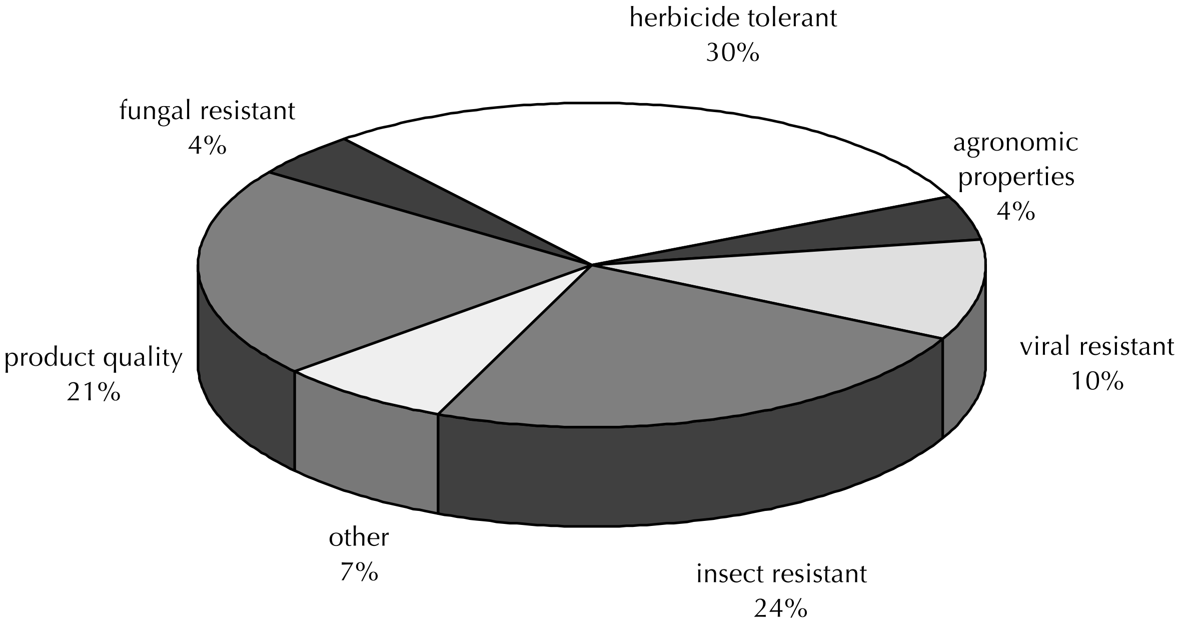
Table 4: Transgenic Crop Field Trials in Canada 1990, 1995, 1997: Most Frequent Crops and Traits (expressed as percentage)

Crop	1990	1995	1997
Canola/napus	78	47	39
Canola/rapa	0	14	27
Potato	4	8	19
Soybean	0	6	7
Corn	3	13	2
Wheat	0	1	2
Alfalfa	3	5	2
Others	12	6	2
Total	**100**	**100**	**100**

Trait	1990	1995	1997
Herbicide tolerance	90	74	52
Insect resistance	0	8	15
Virus resistance	5	5	14
Fungal resistance	0	<1	7
Modified oil comp.	0	6	6
Nutritional change	3	<1	2
Stress tolerance	1	4	2
Others	1	2	2
Total	**100**	**100**	**100**

Source: Compiled by Clive James

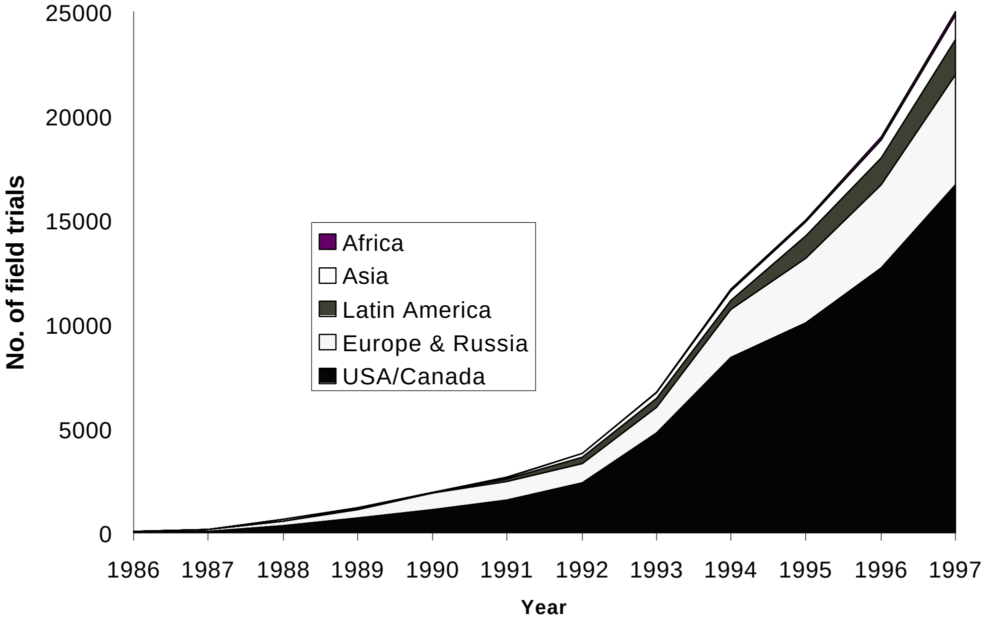
Figure 2: Number of Transgenic Crop Field Trial Sites in the USA, 1987 to 1997: Most Frequent Traits
(expressed as percentage)



Other: Marker Genes Selectable Markers, Bacterial Resistant and Nematode Resistant

Source: APHIS/USDA (Payne, 1997).

Figure 3: Number of Transgenic Crop Field Trial Sites Worldwide by Region, 1986 to 1997



Note: The numbers of field trials in Africa are few, and hence show up only as a line in this graph.

Source: Modified from James and Krattiger (1996).

Review of Transgenic Crop Products Currently Approved for Commercialization

The data in Table 5 shows that, as of year-end 1997, 48 transgenic crop products have been approved for commercialization in at least one country. It is noteworthy that of the 22 technology proprietors listed, 20, equivalent to 90 percent, are private corporations and that only 2, equivalent to 10 percent, are public sector organizations. It is also important to note that all 48 products listed are proprietary products and have been registered as proprietary technology by their respective developers for use in one or more countries. The 48 products involve 12 crops of which corn (36 percent), canola (17 percent), tomato (13 percent) and cotton (11 percent) represent the majority (77 percent) of the crops involved, with the balance made up of soybean, potato, tobacco, squash, 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 (36 percent), quality traits (19 percent), insect resistance (15 percent) and virus resistance (10 percent) represent the majority (80 percent) of approved traits with the balance made up of multiple trait products, insect resistance/herbicide tolerance (10 percent) and hybrid technology/herbicide tolerance (10 percent). The list of 48 approved transgenic crop products listed in Table 5 will change continuously, and probably rapidly, 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 in industrial and developing countries.

Global Status and Distribution of Commercial Transgenic Crops in 1996 and 1997

Information on the global distribution of commercial transgenic crops was obtained from several independent sources in 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 original estimates. Fewer cross checks were possible for China because data is generally much less accessible, and there is a paucity of systematic commercial marketing information that is normally available from private sector corporations which provide transgenic seed to all countries except China. Data in Table 6 shows that the global area planted to commercial transgenic crops increased from 2.8 million hectares (7.0 million acres) in 1996 to 12.8 million hectares, or 31.5 million acres, in 1997. This significant 4.5 fold global increase in area of commercial transgenic crops between 1996 and 1997 represents a very high rate of adoption for this new technology and confirms the eagerness of farmers, particularly those in North America, to invest rapidly in transgenic crops. In 1996, 57 percent of the global transgenic crop area was planted in industrial countries as compared to 43 percent in all developing countries (Table 7), mainly in the Peoples Republic of China with smaller areas in Argentina and Mexico. The area of transgenic crops in industrial countries increased from 57 percent in 1996 to 75 percent in 1997, with only 25 percent of the area planted in developing countries in 1997. The increase in area between 1996 and 1997, expressed as a ratio, was highest for the industrial countries at 5.9, which was more than twice the corresponding ratio for developing countries at 2.7 (Table 7). Thus, between 1996 and 1997 the transgenic crop area in the industrial countries increased more than twice as fast as in developing countries. The actual increase in transgenic crop area between 1996 and 1997 was 7.9 million ha., or 19.5 million acres in industrial countries, and 2.0 million ha., or 5.0 million acres in developing countries.

Distribution of Transgenic Crops, by Country

Despite the fact that China was the first to plant commercial transgenic crops in the early 1990s, by 1996 USA had the largest area of transgenics at 1.5 million ha, or 3.6 million acres, representing 51 percent of the global acreage, compared with China's 39 percent global share (Table 8). In 1996 USA and China collectively had 90 percent of the global area of transgenic

Table 6: Global Area of Transgenic Crops in 1996 and 1997 (millions of hectares/acres)

	Hectares (million)	Acres (million)
1996	2.8	7.0
1997	12.8	31.5

Increase in acreage from 1996 to 1997 is 4.5 fold

Source: Clive James.

Table 5: Transgenic Crops Approved for Commercialization, listed by Technology Proprietor and Transgenic Crop, 1997

Company	Transgenic Crop
AgrEvo Canada Inc.	Glufosinate Tolerant Canola Glufosinate Tolerant Corn
AgrEvo USA Co.	Glufosinate Tolerant Corn Glufosinate Tolerant Canola (import)
Agritope, Inc.	Modified Fruit Ripening Tomato
Asgrow Seed Co.	Virus Resistant Squash I Virus Resistant Squash II
BASF	Sethoxydim Herbicide Tolerant Corn
Bejo-Baden	Male Sterility/Glufosinate Tolerant Chicory
Calgene Inc.	Flavr Savr™ Tomato Bromoxynil Tolerant Cotton Laurate Canola Insect Protected and Bromoxynil Tolerant Cotton
China	Virus Resistant Tomato Virus Resistant Tobacco
Cornell University/Hawaii Growers Assoc.	Virus Resistant Papaya
DeKalb Genetics Corp.	Glufosinate Tolerant Corn Insect Protected Corn Insect Protected and Glufosinate Tolerant Corn
DNA Plant Technology	Improved Ripening Tomato
Du Pont	Sulfonylurea Tolerant Cotton High Oleic Acid Soybean
Florigene	Carnations with Increased Vase Life Carnations with Modified Flower Color
Monsanto Co.	Glyphosate Tolerant Soybean Improved Ripening Tomato Insect-Protected Potato Insect-Protected Cotton Glyphosate Tolerant Cotton Glyphosate Tolerant Canola Insect-Protected Corn Glyphosate Tolerant Corn Insect Protected and Glyphosate Tolerant Corn
Mycogen	Insect-Protected Corn
Novartis Seeds	Insect-Protected Corn Insect-Protected/Glufosinate Tolerant Corn Insect-Protected/Glufosinate Tolerant Sweet Corn
Pioneer Hi-Bred International	Insect-Resistant Corn
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/Glufosphate Tolerant Corn Fertility Restorer/Glufosinate Tolerant Corn
Rhone-Poulenc	Bromoxynil Tolerant Canola
Seita	Bromoxynil Tolerant Tobacco
University of Saskatchewan	Sulfonylurea Tolerant Flax
Zeneca/Petoseed	Improved Ripening Tomato

Source: Compiled and updated by Clive James, based on initial data provided by Fuchs and others 1997.

Table 7: Global Area of Transgenic Crops in 1996 and 1997: Industrial and Developing Countries
(millions of hectares/acres)

	1996			1997			Increase 1996-97		
Region	**Ha**	**Acres**	**%**	**Ha**	**Acres**	**%**	**Ha**	**Acres**	**Ratio**
Industrial countries	1.6	4.0	57	9.5	23.5	75	7.9	19.5	5.9
Developing countries	1.2	3.0	43	3.3	8.0	25	2.0	5.0	2.7
Total	**2.8**	**7.0**	**100**	**12.8**	**31.5**	**100**	**9.9**	**24.5**	**4.5**

Source: Compiled by Clive James.

Table 8: Global Area of Transgenic Crops in 1996 and 1997: By Country
(millions of hectares/acres)

	1996			1997			Increase 1996-97		
Country	**Ha**	**Acres**	**%**	**Ha**	**Acres**	**%**	**Ha**	**Acres**	**Ratio**
USA	1.5	3.6	51	8.1	20.1	64	6.7	16.5	5.6
China	1.1	2.8	39	1.8	4.5	14	0.7	1.8	1.6
Argentina	0.1	0.3	4.0	1.4	3.5	11	1.3	3.3	13.0
Canada	0.1	0.3	4.0	1.3	3.3	10	1.2	3.0	9.2
Australia	<0.1	0.1	1.0	0.1	0.1	<1.0	<0.1	<0.1	1.6
Mexico	<0.1	<0.1	1.0	<0.1	<0.1	<1.0	<0.1	<0.1	10.0
Total	**2.8**	**7.0**	**100**	**12.8**	**31.5**	**100**	**9.9**	**24.5**	**4.5**

Source: Compiled by Clive James.

crops and Argentina and Canada each had an equal 4 percent share, with Australia and Mexico at 1 percent each. Between 1996 and 1997 USA increased its global share of transgenic crop acreage from 51 to 64 percent, equivalent to 8.1 million ha. (20.1 million acres) in 1997, and grew more than four times the transgenic crop area of China, in second place, which decreased to 14 percent of global share in 1997. Whereas China's proportion of global acreage decreased from 39 percent in 1996 to 14 percent in 1997, that of Argentina and Canada increased from 4 to 11 percent and 4 to 10 percent respectively, equivalent to an increase of over one million ha. or over 3 million acres in both countries. Actual area increased significantly in both Mexico (tenfold) and Australia (sixteen fold), but their proportion of global acreage was 1 percent, or below, in both 1996 and 1997. By far the biggest increase in area between 1996 and 1997 was recorded for the USA (6.7 million ha. or 16.5 million acres) equivalent to a 1996/1997 increase ratio of 5.6, followed by Argentina (1.3 million ha.) and Canada (1.2 million ha.). The highest ratios for the increase in area between 1996 and 1997 were recorded for Argentina (13.0), Mexico (10.0), Canada (9.2), USA (5.6) with the lowest for China and Australia at 1.6.

Distribution of Transgenic Crops, by Crop

China's pioneering adoption of transgenic crops in the early 1990s led to a situation in 1996 where tobacco occupied the largest global share, 35 percent, of any crop (Table 9). Insect resistant *Bt* cotton occupied the second largest share at 27 percent, with the largest area in the USA, with some in Australia and Mexico. Soybean occupied 18 percent of the acreage in 1996, with significant areas of herbicide tolerant varieties in the USA and Argentina. Insect resistant *Bt* corn occupied 300,000 ha. in the USA in 1996, equivalent to a share of 10 percent of the global transgenic crop area. Thus in 1996, the top four crops were tobacco (35 percent), cotton (27 percent), soybean (18 percent) and corn (10 percent), collectively occupying 90 percent of the global transgenic crop area, with the balance of 10 percent shared by herbicide tolerant canola (5 percent) in Canada, virus resistant tomato (4 percent) in China, and a small acreage of insect resistant *Bt* potato (< 1 percent) in the USA.

Between 1996 and 1997 there was a significant change in the global share occupied by the different crops. Transgenic soybean ranked first in 1997 accounting for 40 percent of the global acreage and replaced tobacco (which decreased to 13 percent in 1997), which was the highest ranking crop in 1996 with 35 percent of the global area. Global area of transgenic soybean increased tenfold between 1996 and 1997 with most of the increase occurring due to enhanced use of herbicide tolerant soybean in USA and some in Argentina. Corn, which only ranked fourth in 1996 (10 percent of global area) moved up to second position in 1997 with 3.2 million ha. or 7.9 million acres, equivalent to 25 percent of the global transgenic crop area. The eleven fold increase in acreage of corn between 1996 and 1997 was almost entirely due to the use of *Bt* corn in the USA. The proportion of global acreage occupied by transgenic canola increased 9.5 fold between 1996 and 1997 and resulted in canola increasing its global share from 5 percent in 1996 to 10 percent in 1997. Most of this increase was due to a tenfold increase in the area of herbicide tolerant canola in Canada. Although the areas planted to transgenic tomato, cotton, and tobacco increased 2.0, 1.8 and 1.6 fold respectively, their global share decreased because of the relative and significantly higher increases for soybean and corn between 1996 and 1997. Only 4,000 ha. (10,000 acres) of insect resistant potatoes were grown in 1996, mainly in the USA, and although the area increased threefold in 1997, it still only represented less than 0.1 percent of global acreage in 1997. Together soybean (40 percent) and corn (25 percent) occupied almost two-thirds of the global transgenic crop acreage in 1997, followed by tobacco (13 percent), cotton (11 percent) and canola (10 percent), with tomato and potato each occupying one percent or less global share.

Table 9: Global Area of Transgenic Crops in 1996 and 1997: By Crop
(millions of hectares/acres)

	1996			1997			Increase 1996-97		
Crop	**Ha**	**Acres**	**%**	**Ha**	**Acres**	**%**	**Ha**	**Acres**	**Ratio**
Soybean	0.5	1.3	18	5.1	12.5	40	4.6	11.3	10.0
Corn	0.3	0.7	10	3.2	7.9	25	2.9	7.2	11.0
Tobacco	1.0	2.5	35	1.6	4.0	13	0.6	1.5	1.6
Cotton	0.8	1.9	27	1.4	3.5	11	0.6	1.6	1.8
Canola	0.1	0.3	5	1.2	3.1	10	1.1	2.7	9.5
Tomato	0.1	0.2	4	0.1	0.5	1	0.1	0.3	2.0
Potato	<0.1	<0.1	<1	<0.1	<0.1	<1	<0.1	<0.1	3.0
Total	**2.8**	**7.0**	**100**	**12.8**	**31.5**	**100**	**9.9**	**24.5**	**4.5**

Source: Clive James.

Distribution of Transgenic Crops, by Trait

Virus resistance was the dominant trait in the transgenic crop area in 1996 with 40 percent of the global area (Table 10). This was almost entirely due to the significant area of virus resistant tobacco, plus some virus resistant tomato, both of which were planted in China. Insect resistance occupied 37 percent of global share in 1996 and this reflected a significant acreage of *Bt* cotton and a lower acreage of *Bt* corn in the USA. In 1996, herbicide tolerance was first adopted in soybean in the USA and Argentina, and in canola in Canada. Herbicide tolerance, the third ranking trait in 1996, occupying 23 percent of the area, moved to the top ranking position in 1997 with 54 percent of the area. The ratio of 10.7 for the increase in herbicide tolerant soybean between 1996 and 1997 is mainly due to the tenfold increase in area in herbicide tolerant soybean in the USA and Argentina, and to the increase in herbicide tolerant canola in Canada in 1997. The 3.8 fold increase in insect resistance between 1996 and 1997 is largely due to a tenfold increase in *Bt* corn in the USA, and to a smaller increase in *Bt* cotton in the USA. Virus resistance decreased sharply from 40 percent in 1996 to 14 percent in 1997 reflecting the relatively slower growth rate of virus resistant crops, particularly in China, compared with herbicide tolerant and insect resistant crops. The dominant global share of herbicide tolerance (54 percent) in 1997 is noteworthy, followed by insect resistance (31 percent) and the diminishing share of virus resistance; whereas quality traits occupied less than one percent in both 1996 and 1997, they increased threefold in 1997 and this trait category can be expected to increase in the future as output traits become relatively more important than input traits.

Distribution of Transgenic Crops, by Crop/Trait

The self explanatory data in Table 11 show the relative areas occupied by the various crop/trait combinations in 1996 and 1997, and the increase in the respective crop/trait areas between the two years as reflected by the ratio for 1996/97 increase. The major features of the data in Table 11 are the significant increased importance of herbicide tolerance between 1996 and 1997 and its dominance in soybean and canola, and to a lesser extent, cotton, and the sustained importance of *Bt* in cotton and its growing importance in corn. The tenfold increase in herbicide tolerant soybean between 1996 and 1997 resulted in this crop/trait combination moving from third place for 1996 global share (18 percent) to first place in 1997 (40 percent) with the highest ratio (10.2) for the 1996/97 increase in area; tenfold increases were registered both in the USA, where about 75 percent of the herbicide tolerant cotton is grown, and in Argentina where most of the balance is grown. Herbicide tolerant canola, which is exclusively grown in Canada, also had a tenfold increase between 1996 and 1997, although the area occupied in 1997 (1.1 million ha. or 2.7 million acres) is less than one quarter of the area of herbicide tolerant soybean. Herbicide tolerant cotton, grown almost entirely in the USA, with a small area in Mexico, also enjoyed a tenfold increase although the area occupied in 1997 was only 0.3 million ha./ 0.7 million acres, compared with 4.6 million ha. or 11.2 million acres of herbicide tolerant soybean. The tenfold

Table 10: Global Area of Transgenic Crops in 1996 and 1997: By Trait
(millions of hectares/acres)

	1996			1997			Increase 1996-97		
Trait	**Ha**	**Acres**	**%**	**Ha**	**Acres**	**%**	**Ha**	**Acres**	**Ratio**
Herbicide tolerance	0.6	1.6	23	6.9	17.0	54	6.2	15.4	10.7
Insect resistance	1.1	2.6	37	4.0	9.9	31	2.9	7.3	3.8
Virus resistance	1.1	2.8	40	1.8	4.5	14	0.7	1.8	1.6
Insect resistance & herbicide tolerance	--	--	--	<0.1	0.1	<1.0	<0.1	0.1	--
Quality traits	<0.1	<0.1	<1.0	<0.1	<0.1	<1.0	<0.1	<0.1	2.0
Total	**2.8**	**7.0**	**100**	**12.8**	**31.5**	**100**	**9.9**	**24.5**	**4.5**

Source: Clive James.

Table 11: Global Area of Transgenic Crops in 1996 and 1997: By Crop/Trait
(millions of hectares/acres)

	1996			1997			Increase 1996-97		
Crop/Trait	**Ha**	**Acres**	**%**	**Ha**	**Acres**	**%**	**Ha**	**Acres**	**Ratio**
Soybean/ H.T.	0.5	1.3	18.0	5.1	12.5	40	4.6	11.2	10.2
Corn/ I.R.	0.3	0.7	10.0	3.0	7.4	23	2.7	6.7	10.0
Canola/ H.T.	0.1	0.3	4.0	1.2	3.0	10	1.1	2.7	10.0
Cotton/ H.T.	<0.1	<0.1	<1.0	0.4	0.9	3.0	0.3	0.9	10.0
Tobacco/ V.R.	1.0	2.5	35.0	1.6	4.0	13	0.6	1.5	1.6
Cotton/ I.R.	0.8	1.9	27.0	1.1	2.6	8.0	0.3	0.7	1.4
Corn/ H.T.	0.0	0.0	--	0.2	0.6	2.0	0.2	0.6	--
Tomato/ V.R.	0.1	0.3	4.0	0.2	0.5	1.0	0.1	0.2	--
Canola/H.T./H.Y.	0.0	0.0	--	<0.1	<0.1	<1.0	<0.1	<0.1	--
Cotton/ I.R./ H.T.	0.0	0.0	--	<0.1	<0.1	<1.0	<0.1	<0.1	--
Canola (Lauric)	<0.1	<0.1	<1.0	<0.1	<0.1	<1.0	<0.1	<0.1	--
Potato/ I.R.	<0.1	<0.1	<1.0	<0.1	<0.1	<1.0	<0.1	<0.1	--
Tomato (D.Ripening)	<0.1	<0.1	<1.0	<0.1	<0.1	<1.0	<0.1	<0.1	--
Global Totals	**2.8**	**7.0**	**100**	**12.8**	**31.5**	**100**	**9.9**	**24.5**	**4.5**

H.T.: Herbicide Tolerance; I.R.: Insect Resistance; V.R.: Virus Resistance; H.Y.: Hybrid Technology.

Source: Clive James 1997.

increase in *Bt* corn in 1997, most of which was grown in the USA (about 95 percent) with the balance (5 percent) in Canada, catapulted *Bt* corn ahead of *Bt* cotton which occupied more acreage (0.8 million ha. or 1.9 million acres) than *Bt* corn (0.3 million ha./ 0.7 million acres) in 1996. Insect resistant cotton, grown mainly in the USA but with smaller acreages in Australia and Mexico, increased 1.4 fold between 1996 and 1997, and this ratio was approximately the same for the virus resistant tobacco in China. Another feature of the data in Table 11, which will become of increasing importance in the future, is the pyramiding of genes. Whereas the herbicide tolerant hybrid canola and insect resistant/herbicide tolerant canola are the only multiple traits listed in Table 11, multiple trait squash, corn and potato varieties have already been approved and are undergoing seed multiplication.

Summary

Considering the global share of transgenics for the respective countries, crops and traits, the major changes between 1996 and 1997 are correlated with the following features: growth in area of transgenics between 1996 and 1997 in the industrial countries was significant and almost 4 times greater than in developing countries (19.5 million acres versus 5.0 million acres or 7.9 million hectares versus 2.0 million hectares); soybean and corn contributed 75 percent of the global growth in transgenics between 1996 and 1997; herbicide tolerance was responsible for 63 percent (15.4 million acres or 6.2 million hectares) of the global growth in transgenics between 1996 and 1997, with insect resistance contributing 30 percent and virus resistance only 7 percent. The principal phenomena that have influenced the change in absolute area of transgenic crops between 1996 and 1997 and the relative global share of different countries, crops and traits are: firstly, the enormous increase in 1997 of herbicide tolerant soybean in the US and to a lesser extent in Argentina; secondly, the significant increase in 1997 of insect resistant corn in North America; and thirdly, the large increase of herbicide tolerant canola in Canada in 1997. Collectively these three phenomena resulted in a global acreage in 1997 that was 4.5 times higher than 1996, and the relative importance of transgenic tobacco and tomato in China, which was significant in 1996, decreased markedly in 1997 in a global context. In 1997, transgenic soybean, corn, cotton and canola represented 86 percent of the global transgenic area, of which 75 percent was grown in North America with herbicide tolerant soybean being the most dominant transgenic crop followed by insect resistant corn and herbicide tolerant canola.

Assessment of Benefits from Use of Transgenic Crops

Transgenic tobacco was commercialized in China as early as 1992, but it was not until 1994 that transgenic crops were first commercialized in North America and a significant commercial acreage was not reported for the USA and Canada until 1996. More comprehensive information on the benefits associated with the new transgenic crops will have to await a detailed analysis of the 1997 data, when the first substantial acreage of transgenic crops was planted globally. An assessment of some of the benefits associated with the early introduction of transgenic tobacco in China is presented here, as well as information on selected transgenic crops planted in the USA and Canada in 1996, and *Bt* corn in the USA in 1997; these are summarized below on a case by case basis.

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 transgenic virus resistant tobacco, sown commercially in China since 1992, is used nationally for tobacco manufacturing; the area is expected to grow to occupy up to 70 percent of national tobacco acreage by the end of the decade. Virus resistant genetically modified tobacco 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 (James and Krattiger 1996).

Bt Cotton in USA in 1996

The *Bt* cotton planted in the USA in 1996 provided season-long control of some of the major lepidopteran pests including tobacco budworms, cotton bollworms and pink bollworms. The protein from *Bacillus thuringiensis* affects only the target pests leaving beneficial insects unharmed - this is an important benefit in that it facilitates the implementation of Integrated Pest Management (IPM) including the practice of biological control methods. In 1996 two varieties of *Bt* cotton were planted on 0.7 million ha. or 1.8 million acres in the USA by approximately 5,600 growers. In addition, 75,000 acres of *Bt* cotton were planted in Australia and another 5,000 acres in Mexico. The use of *Bt* Cotton has been carefully monitored in Alabama by Smith (1997, 1998) whose studies were initiated in 1995 and continued in 1996 and 1997. Smith reported that the cotton insect pest infestations in Alabama were high in 1995, low in 1996, medium in 1997, with overall excellent control of the budworm and bollworm cotton pests with pest escapes in *Bt* cotton not causing economic losses. Of the 5,600 farmers who planted transgenic cotton in the USA in 1996, 70 percent did not require any insecticide application for the targeted insect pests, whereas most others had to apply only one application compared with the four to six insecticide sprays that are normally applied to non-transgenic cotton varieties. The use of *Bt* cotton in the USA in 1996 is estimated to have eliminated the use of approximately 250,000 gallons of insecticide on cotton and the corresponding financial and environmental costs involved. Yield increases of *Bt* cotton, compared with non-*Bt* cotton varied with the level of pest infestation and were as high as 20 percent, with an average yield increase of 7 percent. For *Bt* cotton, insecticides savings were as high as $ 60 to $ 120 per acre ($ 140 to $ 280 per ha.) whilst US farmers paid a technology fee of $ 32 per acre. Thus, insecticide savings, along with an average yield increase of 7 percent for *Bt* cotton, are estimated to have resulted in a net saving of $ 33 per acre (Krattiger 1997, Monsanto 1997). Applying this net benefit of $ 33 per acre to the 1.8 million acres in the USA in 1996 is estimated to have resulted in an overall benefit to USA farmers who planted *Bt* cotton in 1996 of approximately $ 60 million, excluding the environmental benefits associated with eliminating insecticide applications. Extrapolation of these benefits to the total acreage in the USA is not appropriate and not recommended because relative importance of insect pests for different regions of the USA, and pest infestation for different years, will vary. In 1996 some farmers in areas of Texas, where insect infestation on cotton was unusually high, claimed to have suffered losses from cotton bollworm damage on 18,000 acres (Myerson 1997); a similar situation was reported with herbicide tolerant cotton on a small acreage in the Mississippi Delta and Texas in 1997 that has been attributed to possible interactions of many factors including variety, weather and management practices (Myerson 1997). With the introduction of any new technology there will always be site-specific situations which will require fine-tuning of the technology and its management, and new biotech products will be no different to conventional products. In considering such instances where, for example, the technology may not have performed to the expectations of farmers on 18,000 acres of Bt cotton, it is equally important to consider the benefits enjoyed by the 99.9 percent of farmers on the balance of 1.8 million acres of *Bt* cotton. Probably the most important endorsement for *Bt* cotton planted in the USA in 1996 was that an estimated 98 percent of farmers who planted *Bt* cotton in 1996 planned to replant *Bt* cotton in 1997; records confirm that the area planted to *Bt* cotton in 1997 increased by 43 percent to reach 2.5 million acres (1.0 million ha.), equivalent to 18 percent of the 14 million USA cotton acreage in 1997. Internationally, the potential substitution value for cotton insecticides used for the control of bollworm alone has been estimated to be $ 807 million annually (Krattiger 1997), so the potential financial and environmental benefits of *Bt* cotton are enormous, provided that effective management schemes can be implemented to maximize the durability of the *Bt* genes deployed.

Herbicide Tolerant Soybean in USA in 1996

Herbicide tolerant soybeans were grown on approximately 1 million acres (0.4 million ha.), equivalent to approximately 2 percent of the US soybean acreage of 64 million acres in 1996, and planted by approximately 10,000 farmers; an additional 250,000 acres (100,000 ha.) were grown in Argentina. In the USA, seed was sold by three companies. The herbicide tolerant gene has no effect on yield *per se* but significantly better weed control is achieved, which in turn increases yield dependability. However, more importantly 75 percent of farmers using herbicide tolerant soybean required only one application of herbicide, and with the exception of 2 percent of farmers who applied 3 applications of herbicides, the balance of 23 percent only applied 2 herbicide applications. This decreased requirement for herbicides on herbicide tolerant soybean, translated to herbicide savings of 10 to 40 percent which has substantial economic implications as well as environmental benefits. In addition to improved weed control, cultivation of herbicide tolerant soybean provides significant agronomic management advantages that include increased flexibility, no carry-over of residues, better yield dependability, improved soil and moisture conservation, compatibility with tillage conservation that reduces soil erosion, which is a critically important factor for some soils, particularly in fragile ecosystems. Grower satisfaction in the USA with the product was very high, as evidenced by a tenfold increase in area between 1996, when 10,000 farmers grew 1 million acres (0.4 million ha.), and 1997 when more than 50,000 farmers grew 9 million acres (3.6 million ha.), equivalent to 13 percent of the 71 million national acreage of soybean in the USA in 1997.

*Bt C*orn in USA in 1996 and 1997

Bt corn planted in the USA in 1996 provided control of European corn borer, one of the most important insect pests of corn in the USA (Novartis 1997). The protein from *Bacillus thuringiensis* (*Bt*) affects only the target pest and does not affect beneficial insects. Of the 79 million acres (32 million ha.) of corn grown in the USA in 1996, it is reported that 50 percent, equivalent to almost 40 million acres (16 million ha.), was infested with European corn borer, which does not easily lend itself to control with insecticides, and hence farmers suffer from almost the full potential loss to the pest. It is estimated that yield loss due to European corn borer in the USA can be as high as 30 percent, with an average loss of 9 percent; based on these estimates the annual value of the loss due to European corn borer in the USA in 1996 was approximately $ 1 billion. In 1996, 700,000 acres of *Bt* corn were planted in the USA and the actual average increase in yield was measured at 9 percent - early results for 1997 also confirm an average increase in yield with *Bt* corn of 9 percent equivalent to a net gain of $ 27.25 per acre (Monsanto 1997); based on these estimates reported for 1996 and 1997, the benefits from *Bt* corn in the USA in 1996 were of the order of $ 19 million, and $ 190 million in 1997, excluding the savings on insecticides applied for the control of European corn borer to a small proportion of the corn acreage in the USA. Thus, the estimated potential benefit from using *Bt* corn on all the corn acreage infested by European corn borer in the USA confirms the original estimate of approximately $ 1 billion annually. Grower satisfaction in 1996, when *Bt* corn represented approximately 1 percent of the national acreage led to a tenfold increase in 1997 when Bt corn occupied 7 million acres, or 9 percent of the 80 million national corn acreage in the USA in 1997.

Herbicide Tolerant Canola in Canada in 1996

Herbicide tolerant canola was grown on 300,000 acres (120,000 ha.) in Canada in 1996 by more than 2,500 growers. The herbicide tolerant genes have no effect on yield *per se* but improved weed control is achieved and hence this increases both yield and yield dependability. Average yield of herbicide tolerant canola in Canada in 1996 was 9 percent greater than non-herbicide tolerant canola treated with other weed control alternates. In addition, farmers required less herbicides on the herbicide tolerant canola; one report indicates that 80 percent of farmers using herbicide tolerant canola required only one application of the respective herbicide (Monsanto 1997); another report (AgrEvo 1997) indicated that herbicide requirement decreased from 570 grams to 160 grams active ingredient per acre (equivalent to 1,400 grams to 400 grams per ha.) with coincidental yield increases of up to 20 percent. Seed quality of herbicide tolerant canola also improved because fewer weed seeds were mixed with the canola grain which also had a higher proportion of #1 Grade, 85 percent, versus 63 percent in non-herbicide tolerant varieties. Use of herbicide tolerant canola had important agronomic and management advantages in that it allowed better soil and moisture conservation, much more flexibility in weed control, and facilitated tillage conservation that can significantly reduce the very important problem of soil erosion and hence can make a critical contribution to a more sustainable agriculture. Again, grower satisfaction with the product was very high in 1996 and this led to almost a tenfold increase in area of herbicide tolerant canola in 1997 when 3.0 million acres (1.2 million ha.), equivalent to 25 percent of the total of 12 million acres of canola grown in Canada in 1997), were grown by up to 25,000 farmers. Considering yield increase, reduced herbicide and seed costs, a conservative estimate of the net gain to farmers is $ 20 per acre ($ 50 per ha.), hence the total benefits for the 300,000 acres of herbicide tolerant canola grown in 1996 in Canada were approximately $ 6 million. Assuming that similar benefits would apply broadly to the total Canadian acreage of 9.0 million acres, of which only 3 percent was occupied in 1996, the potential annual benefits from using herbicide tolerant canola in Canada in 1996 would have been of the order of $ 180 million. In addition, the application of the benign environmental herbicides, that are currently used on herbicide tolerant canola, result in very significant environmental benefits because the herbicides breakdown in soil, do not contaminate groundwater and do not accumulate in the food chain.

Bt Potatoes in USA in 1996

In 1996 approximately 9,000 acres of insect resistant potatoes, variety Russet Burbank, were grown in the USA and an additional 1,000 acres in Canada. The transgenic insect resistant potatoes offered a season-long control against the Colorado potato beetle, which is considered the most devastating insect pest of potatoes in North America. The protein from *Bacillus thuringiensis* (*Bt*) affects only the Colorado potato beetle and does not affect any of the beneficial insects that can be important elements in integrated pest management, strategies and biological control programs. Preliminary results from the USA for 1996 indicate that farmers using *Bt* potatoes were able to reduce the number of insecticide applications for the control of Colorado beetle by an average of 1.2 sprays that resulted in an average saving of $ 5 per acre ($ 12 per ha.), based on insecticide control costs of $ 30 to $ 120 per acre or $ 75 to $ 300 per ha. in the USA. In addition to savings on insecticides, farmers using *Bt* potatoes in the USA in 1996 reported an average increased return of $ 14 per acre ($ 35 per ha.) from *Bt* potatoes (compared with the non-*Bt* variety) which was due to the improved size, shape and quality of the potatoes. Thus, the net benefit from *Bt* potatoes in the USA in 1996 was $ 19 per acre (Monsanto 1997) equivalent to a total national benefit of $ 170,000 on 9,000 acres. Grower satisfaction with *Bt* potatoes in the USA in 1996 was high and 96 percent reported that they would replant *Bt* potatoes in 1997 when the actual area of *Bt* potatoes in the USA increased 2.5 fold to 25,000 acres (10,000 ha.); the *Bt* potato acreage is expected to increase significantly in 1998. Colorado beetle is a devastating pest in many of the potato growing areas of the world; global acreage of potatoes is over 18 million ha. with a production of 275 million tons of potatoes annually. Of the field and vegetable crops, the potato crop is one of the heaviest users of pesticides consuming more than $ 360 million worth of insecticides in 1996 (Wood Mackenzie 1997). Thus, there is significant global potential for substantial benefits from *Bt* potatoes provided that effective management and deployment strategies can be implemented for maximizing the durability of the current *Bt* genes that are being deployed or the alternate *Bt* or other genes that are being developed.

Summary

It is evident that the preliminary analysis of benefits for the case studies detailed above indicate that there are significant and multiple benefits associated with the use of transgenic crops in China, in the USA and Canada in 1996 and from *Bt* corn in the USA in 1997. More comprehensive information on the benefits associated with new transgenic crops will be available following analysis of 1997 data, when a substantial acreage of transgenics was planted globally. An initial assessment of the benefits from transgenic crops is reported here: virus resistant tobacco in China has increased leaf yield of 5 to 7 percent and savings of 2 to 3 insecticide applications; insect resistant *Bt* cotton in the USA in 1996 resulted in insecticide savings as high as $ 60 to $ 120 per acre ($ 140 to $ 280 per ha.), with 70 percent of *Bt* cotton planted in 1996 requiring no insecticides for the targeted insect pests, and resulting in up to a 20 percent increase in yield, depending on the severity of the infestation, with an average yield increase of 7 percent - this resulted in a net benefit of $ 33 per acre for a total benefit of $ 60 million for Bt cotton in the USA in 1996; borer-resistant *Bt* corn in USA produced up to 20 percent more yield with an average yield increase of 9% in 1996 and 1997 - 50 percent of the 80 million US corn acreage, equivalent to 40 million acres (16 million ha) is reported to be infested with European corn borer, with an estimated annual loss of $ 1 billion - benefits from the use of *Bt* corn in the USA were estimated at $ 19 million in 1996 and $ 190 million in 1997; herbicide tolerant soybean in USA in 1996 resulted in 10 to 40 percent less herbicide requirements, better control of weeds and soil moisture conservation, improved yield dependability, no carry-over of herbicide residues and much more flexibility in agronomic management of the crop; herbicide tolerant canola in Canada in 1996 lowered herbicide requirements, for example, from 570 grams to 160 grams active ingredient per acre (1,400 grams to 400 grams per hectare), increased yield up to 20 percent, with an average yield of 9 percent, improved yield dependability, no carry-over of herbicide residues, more flexibility in agronomic management, plus a higher proportion of #1 Grade canola, 85 percent versus 63 percent, as well as better soil and moisture conservation; insect resistant *Bt* potatoes in USA in 1996 resulted in effective control of Colorado beetle, yield/quality benefits per acre of $ 14 and insecticide savings of $ 5, for net benefits of $ 19 per acre that total $170,000 of benefits for *Bt* potatoes in the USA in 1996. Thus, at a national level in the USA in 1996, the total benefits for *Bt* cotton, corn and potato were $ 80 million, and $ 190 million for *Bt* corn alone in 1997 (Table 12); similarly at the national level the benefits from herbicide tolerant canola in Canada in 1996 were $ 6 million. In general, transgenic crops have been well received in North America, with a very high percentage of farmers who planted transgenic crops in 1996 electing to plant again in 1997; many transgenic products were unavailable to potential growers in North America in 1997 because of shortage of transgenic seed supplies, thus reducing the potential area planted to transgenic crops.

Table 12: Estimated Economic Benefits Associated with Selected Bt Transgenic Crops in the USA, 1996 and 1997

	1996			1997		
Crop	**National Acreage** (millions)	**Transgenic Crop Acreage** (%)	**Benefits** ($ millions)	**National Acreage** (millions)	**Transgenic Crop Acreage** (%)	**Benefits** ($ millions)
Cotton	14	13.0	60[1]	14	18.0	n.a.
Corn	79	0.9	19[2]	80	9.0	190[2]
Potato	1	0.9	<1[3]	1	2.4	n.a.

n.a. Not available.

Based on net returns per acre of:
[1] $33.00
[2] $27.25
[3] $19.00

Adoption of Transgenic Crops and Status of the Technology

Many factors will affect and contribute to the expected continued growth of transgenic crops during the next five years; some of the principal factors are discussed here. The current generation of commercialized agronomic "input traits" will continue to expand allowing more biotic and abiotic stresses to be addressed through biotechnology solutions. "Output traits" that will improve the nutritional content of foods and feeds will become increasingly important, relative to input traits, initially in the industrial countries and this trend will ultimately extend to the more advanced developing countries. One of the most effective methods to assess the most promising new input and output traits, is to review the traits that are already at an advanced stage of development and being tested in field trials; a selection of field trials for specific crops and selected countries will be reviewed here for this purpose. At the same time that new traits will become available, adoption rates for major transgenic crops, such as soybean, corn, canola, cotton and potato, that have already been commercialized in countries such as USA and Canada will increase from the current rates of 1 to 10 percent of national acreage to 25 to 50 percent, or more; this trend, which will first be evident in North America is expected to quickly extend to countries such as Australia, Argentina and Mexico. Growth of transgenic crops will continue in China, both in terms of increased adoption rates for crops already commercialized and new transgenic crops that will be introduced.

Simultaneously, penetration of new markets will occur at different growth rates in most of the regions of the world. In Europe, countries such as Turkey are likely to be early adopters of transgenic crops, along with selected members of the European Union (subject to resolution of issues in relation to labeling, freedom of choice, use of antibiotic resistant markers, and other considerations) and the Eastern European countries including the Russian Federation which is likely to commercialize transgenics in the next few years. Expansion of transgenic crops will continue in Latin America to countries such as Brazil and Chile in the MERCOSUR trading region and to some of the more advanced countries on the continent such as Venezuela. Transgenic crops will be embraced more in Asia as Japan approves more products, as the expansion continues in China, and Singapore stimulates more interest in biotechnology following its recent significant increased investments in agri-biotechnology R&D. Despite the lack of operational biosafety regulations in many developing countries in Asia (which currently precludes the critical step of field testing transgenic crops in many countries), countries such as India, Thailand, Malaysia, Philippines, Indonesia and Vietnam increasingly recognize the significant benefits that can accrue from transgenic crops in the near-term, and conversely the comparative disadvantage associated with non-adoption of the new technologies. Transgenic crops are also being assigned higher priorities by countries such as Egypt, and other countries in the North African, Middle and Near East Region, which assign a high priority to food security and to foreign exchange earnings from export commercial cash crops such as cotton. Commercialization of transgenic crops is expected to occur in South Africa in the near-term and countries such as Kenya plan to initiate field testing of transgenic crops in the next year or so.

The commercialization of transgenic crops for the first time in North America provided companies the opportunity to explore new marketing concepts, and corporations have evolved different strategies to market their products. Most companies have marketed the new transgenic seed in exactly the same way as traditional hybrids and varieties. In these cases the price of the improved transgenic seed has been determined taking into account the additional benefits that are conferred through the incorporation of transgenic traits. Other corporations, for example Monsanto, charge a separate fee for the transgenic technology. In the USA, for the Bt traits, contracts between the vendors of the transgenic seed and farmers have been introduced to ensure the implementation of an appropriate management program for the Bt genes that entails the planting of a refuge crop. The concept of a refuge is based on the assumption that the development of resistance in the pest is a likely event in any pest control program, so proactive management of the Bt cotton gene to maximize durability of the gene is the major goal of the refuge contract between the seed company and individual farmers.

The data in Table 13 compares the traits that have already been commercialized in selected crops and traits that are at an advanced stage of testing in field trails, or under development. For the eight major crops listed, canola, corn, cotton, potato, rice, soybean, tomato, and vegetables/fruits, a total of 17 products have already been commercialized whereas almost twice that number of products (35) are in field trials or under development; this confirms that the number of transgenic crop products is increasing and that the R&D pipeline is full of new transgenic products, many of which are in the advanced stage

Table 13: Traits already Commercialized in Field Trials, and under Development for Selected Crops, 1997

Crop	Traits already commercialized	Traits in Field Trials/Development
Canola	1. Herbicide tolerance 2. Hybrid technology 3. Hybrid technology and herbicide tolerance 4. High lauric acid	1. Improved disease resistance 2. Other oil modifications
Corn	1. Control of Corn-Borer 2. Herbicide tolerance 3. Insect protected/herbicide tolerance 4. Hybrid technology 5. Hybrid/herbicide tolerance	1. Control of Asian Corn-Borer 2. Control of Corn Rootworm 3. Disease resistance 4. Higher starch content 5. Modified starch content 6. High lysine 7. Improved protein 8. Resistance to storage grain pests 9. Apomixis
Cotton	1. Bollworm control with single genes 2. Herbicide resistance 3. Insect protected/herbicide tolerance	1. Bollworm control with multiple genes 2. Control of Boll Weevil 3. Improved fiber/staple quality 4. Disease resistance
Potato	1. Resistance to Colorado Beetle	1. Resistance to Colorado Beetle + Virus resistance 2. Multiple Virus resistance (PVX, PVY, PLRV) 3. Fungal disease resistance 4. Higher starch/solids 5. Resistance to potato weevil/storage pests
Rice		1. Resistance to bacterial blight 2. Resistance to rice-borers 3. Fungal disease resistance 4. Improved hybrid technology 5. Resistance to storage pests 6. Herbicide tolerance
Soybean	1. Herbicide tolerance 2. High oleic acid	1. Modified oil 2. Insect resistance 3. Virus resistance
Tomato	1. Delayed/Improved ripening	1. Virus resistance 2. Insect resistance 3. Disease resistance 4. Quality/high solids
Vegetables & Fruits	1. Virus resistance	1. Insect resistance 2. Delayed ripening

Source: Clive James 1997

of development and likely to be available in the near-term; longer-term research on the more challenging abiotic stresses, controlled with multiple genes, including drought tolerance, salt tolerance and aluminum tolerance is underway and some encouraging progress is being made. It is noteworthy that of the 17 commercialized products in Table 13, four, equivalent to 24 percent, have double traits, indicating that the process of pyramiding genes through biotechnology has already been initiated and is expected to accelerate in the near-term. In the past, conventional crop improvement programs have aimed to pyramid as many beneficial genes as possible in improved varieties. Biotechnology represents an additional means of pyramiding, and for incorporating genes that could not be transferred through conventional breeding programs. Thus genes such as Bt from a soil bacterium to confer resistance to selected insect pests as well as genes conferring non-conventional virus resistance and herbicide tolerance and genes for higher starch content can all be incorporated and pyramided in the same improved variety.

In any crop improvement program it is important to maintain biodiversity which can be sustained through ensuring that the broad germplasm base is not narrowed as a result of crop improvement; this is equally important for conventional and biotechnology crop improvement programs. Aware of this need, an effort has been made from the outset by owners of proprietary biotechnology products and seed companies to provide as diverse a genetic base as possible to ensure biodiversity in biotechnology products and to provide growers with a broad choice of germplasm that is well adapted to the different agro-environments where crops are grown. For example, the initial two transgenic varieties of cotton that were available in 1996, were increased to ten in 1997 and expected to increase to 28 in 1998. Only a few transgenic corn varieties were available initially in 1996, but the number supplied by different companies increased to 30 - 50 varieties in 1997, and this is expected to double in 1998. Similarly, the number of transgenic potato varieties increased from one in 1996 to four in 1997 and similarly for canola the numbers increased significantly between 1996 and 1997 and are expected to more than double between 1997 and 1998. Diversity in transgenic crop germplasm is enhanced as a result of intensive collaboration and licensing between the proprietors of biotechnology applications and seed companies. For example, in 1997 Monsanto collaborated with over 85 soybean seed companies and well over 100 herbicide tolerant transgenic varieties were available on the market - this is expected to increase to over 300 in 1998 (Monsanto 1997).

The evolving trend for output traits, as compared to input traits, to become relatively more prevalent and important over time, is supported by the data in Table 13. Of the 17 commercialized products listed in Table 13 only three, equivalent to 18 percent, are quality “output traits” whereas 11 out of 35 traits, equivalent to 31 percent, are output traits in the later generation of products that are currently being field tested or under development. The twenty-first century is likely to be an era of specialized food and feed products that will be created from conventional commodities through the use of biotechnology applications. Thus the traditional food and feed products that have been marketed simply as commodity products will probably undergo a revolutionary change where specific traits will be pre-engineered through biotechnology to serve specialized and high value niche markets. Whereas these specialized products will have higher value they will also have a cost in that they will require special handling from the farm through processing, and ultimately to the consumer. Thus, in future, biotechnology will not only be used to overcome biotic and abiotic traits through improved agronomic characteristics but to develop specialty products designed for health, nutrition, taste, and for new processing methods. For example, the traditional corn wet milling industry uses enzymes to convert starch into high fructose corn syrup. In future, corn with higher starch content will add value at the farmer level as well as contributing to a higher output of the corn wet milling industry which can simultaneously derive environmental and cost benefits from starch modification that will require less use of chemicals during the wet milling process

A review of products already commercialized and being tested in field trials, or under development by selected countries, confirms that the R&D pipeline is full of new transgenic products that are likely to be available in the near-term. The data in Table 14 summarizes the transgenic crop products for China. To date, China has planted large areas of three products: virus resistant tobacco, virus resistant tomato and a tomato with modified ripening. Products in field trials in China, will, in the near-term probably increase the number of transgenic products from 3 to 13, expand the range of transgenic crops from 2 to 9, and the number of traits from 2 to 5. The broad range of transgenic crops in field trials in China include rice, the most important crop in Asia, maize, soybean, cotton, potato, papaya, and sweet pepper. The expanding range of

Table 14: Traits Already Commercialized, in Field Trials and under Development in China, 1997

Crop	Trait
Commercialized crops	
Tobacco	Virus resistance
Tomato	Virus resistance
Tomato	Quality-modified ripening
Field trials	
Cotton	Insect resistance
Maize	Insect resistance
Papaya	Virus Resistance (Ring Spot)
Potato	Disease Resistance (Bacterial Wilt)
Rice	Insect resistance
Soybean	Herbicide tolerance
Soybean	Insect resistance
Sweet Pepper	Virus resistance
Tobacco	Disease resistance
Tobacco	Insect resistance

Source: National Program, China; Compiled by Clive James traits are equally impressive, including insect resistance for corn borers in rice which include 5 species and considered by some (Barr et al. 1975) to be the most serious pests; stem borers of rice annually require approximately $ 450 million of insecticides which could be substituted by *Bt* or alternate products with substantive economic and environmental benefits. Insect resistance for cotton, a major crop in China that consumes an enormous amount of insecticides, could also provide significant economic and environmental benefits; the same applies to maize where corn borers are major pests that lend themselves for control with current biotechnology applications. Bacterial diseases, that have eluded control through conventional technology, represent potentially important breakthroughs for biotechnology, which are already being tested by China for the control of bacterial wilt of potato, and similar gene technology is also proving effective in controlling bacterial blight of rice, which is an endemic and important disease of rice in Asia.

China, which is already using anther culture in rice, leads the way in introducing and adopting the first transgenic rice in Asia and this will be of major significance from many viewpoints. The initial experience of introducing transgenic rice in Asia will provide important new information on issues in relation to environmental release, the role of biotechnology in adopting rice production systems to meet the future, and rapidly changing, agronomic management practices of rice production in Asia. Given that rice is part of the foundation of Asian culture, the potential impact of biotechnology on rice culture in China, and Asia, cannot be overstated, and accordingly the initiative requires the very careful and prudent management that it deserves, and will undoubtedly receive. It is also highly probable that future biotechnology applications in China will, unlike the past, involve substantial formal collaboration and involvement of external partners, particularly private sector companies; whereas collaboration between China and the international centers of the CGIAR will continue on the major staples, cooperation has also recently been extended to other public sector organizations such as the new Institute of Molecular Agrobiology (IMA) of the National University of Singapore, which is collaborating with China and with the private sector. It is noteworthy that throughout history rice has been a crop that has been carefully regulated in the public domain, and the advent of biotechnology probably provides the first opportunity for the global private sector, with significant investments and capability in biotechnology, to make a substantive and appropriate contribution to increased and more sustainable productivity of rice in China and Asia. IRRI, which has made significant investments in rice biotechnology also has many important biotechnology applications to offer its Asian partners; the most appropriate genetic engineering opportunity for the near-term is a gene for the control of bacterial blight of rice, particularly the Xa-21 gene. China's early involvement in biotechnology and its positive experience with the transgenic products to-date, is a very important experience to share with the rest of Asia, where the lack of operational biosafety regulations currently precludes biotechnology from making an important contribution to the region in the world that has the most to gain from the new technologies, where 60 percent of the global population resides and where 50 percent of the world's poor people try to survive, and millions suffer from malnutrition.

Australia is unique among the industrial countries in that it has significant and productive public sector investments in biotechnology. The data in Table 15 indicate that Australia has already commercialized three transgenic products. Crops in advanced field trials in Australia will probably expand the range of transgenic crops from 2 to 12. New transgenic crops would include canola, field pea, lupin, potato, subterranean clover, sugar cane, tobacco, tomato, wheat and white clover. Similarly the new traits being field tested in Australia would expand the range of potential traits from 3 to 12, to include herbicide tolerance, male sterility, various quality aspects (including sunflower albumin, anti-browning, and starch modification) and virus resistance. The field trials on wheat, involving herbicide resistance and modification to starch quality are important because technological constraints have, to date, delayed commercialization of transgenic wheat, and denied countries, in both the industrial and developing world, the significant potential benefits that can accrue, given the global importance of the crop and the prevalence of biotic and abiotic productivity constraints.

Mexico's success with transgenic crops is impressive in that it has already commercialized 3 transgenic products (Table 16). Whereas all three of the commercialized products have been developed by external private sector corporations, Mexico has the distinction of being one of the first developing countries, along with China and Cuba, to field test a transgenic virus resistant potato that its own national scientists developed in a research project, brokered by ISAAA in cooperation with Monsanto, and funded by the Rockefeller Foundation (James 1991). Mexico's portfolio of current field tested transgenic crops has increased its experience of transgenic crops from 2 to 15 crops; the new crops include maize which is vital to the country's food security, potato, an important staple for the poor people in the highlands, and wheat, for which

Table 15: Traits Already Commercialized, in Field Trials and under Development in Australia, 1997

Crop	Trait
Commercialized crops	
Cotton	Insect Resistance Bt.
Carnation	Longer vase life
Carnation	Modified flower color
Field trials	
Canola	Herbicide Tolerance
Canola	Male sterility
Field Pea	Quality
Field Pea	Quality - Sunflower Albumin
Lupin	Insect Resistance - Pea Weevil
Lupin	Herbicide Tolerance
Potato	Quality - Sunflower Albumin
Potato	Quality - Anti-browning
Subterr. Clover	Virus Resistance – PLRV
Sugar Cane	Herbicide Resistance
Tobacco	Disease Resistance - Leaf Scald
Tomato	Insect Resistance Bt.
Wheat	Insect Resistance Bt.
Wheat	Herbicide Resistance
Wheat	Quality - Starch Modification
White Clover	Virus Resistance - Alfalfa Mosaic

Source: National Program, Australia; compiled by Clive James.

Table 16: Traits Already Commercialized, in Field Trials and under Development in Mexico, 1997

Crop	Trait
Commercialized crops	
Cotton	Insect resistance
Cotton	Herbicide tolerance
Tomato	Delayed ripening
Field trials	
Alfalfa	Marker gene
Canola	High lauric
Chili Pepper	Delayed ripening
Cotton	Insect resistance & Herbicide tolerance
Maize	Insect resistance
Maize	Herbicide tolerance
Maize	Insect resistance & Herbicide tolerance
Melon	Virus resistance
Papaya	Virus resistance
Potato	Virus resistance
Rice	SPS gene
Soybean	Herbicide tolerance
Squash	Virus resistance
Tobacco	Virus resistance
Tomato	Insect resistance
Tomato	Virus resistance
Wheat	DMRF gene

Source: Sanidad Vegetal, Mexico, 1997; compiled by Clive James.

Mexico is increasingly dependent on imports, purchased with scarce foreign exchange. Herbicide tolerant soybean and canola are important vegetable oil crops in Mexico for both food and feed, and developing virus resistant crops such as tomato, melon, papaya and chili pepper is important to Mexico's growing fruit and vegetable industry. The majority of the new products that Mexico is field testing are for improved crop protection which should significantly decrease the use of insecticides and have substantial environmental benefits. Herbicide tolerance in crops such as maize has the potential to facilitate the adoption of maize in low or zero tillage management systems and contribute to the goal of erosion control, which is particularly important and urgent on marginal land and steep slopes normally cultivated by subsistence farmers. The release of transgenic papaya, resistant to papaya ring spot virus, should also deliver significant benefits to subsistence farmers whose only current option is to suffer the losses due to this devastating disease which is pandemic in all developing countries. Mexico, as a developing country, has the distinction of having a well trained group of biotechnologists at its CINVESTAV laboratory in Irapuato that have the full capacity to develop transgenic crop technology, and is also sharing this experience with national scientists from other countries in Latin America and the Caribbean, to build national capacity in biotechnology; this capacity building in biotechnology in national programs is critical for institutional sustainability and will also greatly facilitate the early adoption and widespread use of transgenic crops in the countries of Latin America and the Caribbean.

In formulating and implementing policies for agricultural biotechnology, national programs in developing countries must be careful not to get distracted by the intriguing attraction of biotechnology as a science and focus sharply on applications that can result in economic benefit and values to farmers, the food industry and the consumers in the near-term. Experience in the industrial countries indicates that it is very important to build broadly-based multidisciplinary teams because those involved with the development of the science and technology often don't understand the marketing issues and the needs of the consumers, and vice versa. Failure to adopt a broad-based holistic approach will result in the development of technology that may not have value in the market place.

Some recent technological developments confirm the earlier hope that, over time, biotechnology research would lead to significant breakthroughs in technological developments that can have a broad impact on crop improvement and a more equitable distribution of benefits. Significant progress has recently been reported in development of apomictic maize by two groups (Anonymous 1997). Apomixis is the process by which plants (that normally multiply through sexual reproduction) reproduce through asexual seeds. Apomixis is of significant importance to crop breeders and biotechnologists because none of the major crops are apomictic. The first initiative is a collaborative effort between the Range Research Station at Oklahoma in the USA, and the Laboratory of Cytology and Genetics in Novosibirk, Russia. The second initiative is at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico. The American/Russian team has produced apomictic maize hybrids through crossing maize and its apomictic relative, gamagrass. Analysis of apomictic hybrids indicate that the genes responsible for apomixis are on Chromosome 16, and the American/Russian team have already received a patent for their apomictic maize plant. In the interim, the group at CIMMYT, which includes a team of French scientists, may have already identified one of the apomictic genes and are attempting to locate others. Incorporating apomictic genes in an important commercial crop, such as maize, is a very significant development because to-date no major crop is apomictic, and the potential implications are far-reaching. If improved varieties of apomictic maize were available, farmers would not have to purchase new hybrid seed annually from seed companies, because the benefits would be retained in their saved seed. Conversely, if apomictic maize was available, seed companies may no longer have the opportunity to replace hybrid seed of maize on an annual basis, unless other technology is developed in conjunction with the apomictic gene that will allow the value of the improved apomictic maize to be captured. One such mechanism would be to incorporate into the apomictic maize, an inducible promoter which would switch on the apomictic gene only on application of a proprietary chemical agent produced and marketed by seed companies. The identification and incorporation of apomictic genes that are operational in economically important crops such as maize, opens up the possibility that these or similar genes can also be employed in other major crops that are currently marketed as hybrids.

Similarly, the early expectations that biotechnology would allow plant products to be modified for use as industrial materials is also showing promise. A team of US scientists at the University of Delaware has recently patented a technique for using soybean oil as a substitute for petroleum-based plastics. Soybean oil has a chemical structure that allows it to be easily manipulated through biotechnology into composites with different specifications; these composite materials are inexpensive, light, composite materials that can be used to replace plastic and metals used for building cars. The soybean composites offer many advantages including the following: can be produced from a renewable resource in contrast to petroleum which is a non-renewable fossil fuel source; less expensive - the soybean composites which can be synthesized in twelve different specifications (rubbery, thermoplastic, reinforced matrix etc.) cost 30 to 50 cents a pound compared with $1 to $2 a pound with the vinyl latex materials that they will substitute. Deere and Co., a large US-based farm equipment manufacturer is the first customer for the new product, which will replace metal sheeting on some machinery - in contrast to metal it will not corrode or rust and has been made using a low energy process which is more environmentally friendly than metal casting. Future soybean composites could be formulated to be biodegradable and natural products such as straw or hay fibers could replace the reinforcing fiberglass that is currently used. Deere and Co. project a $50 million market for the soybean composition in farm equipment alone, and the potential market for vehicle parts is enormous.

Intellectual Property Rights

With the advent of a new era in science and technology, (biotechnology represents one of the knowledge-based new technologies which also include microelectronics, automation and new materials, information and communication, technologies), the comparative advantage of national programs are becoming less dependent on natural resources, and more dependent on proprietary science and the human skills to evolve, manage and protect intellectual property. During the 1990s intellectual property rights have engaged the attention of governments, policy makers, and scientists in both private and public sectors as the Uruguay Round, GATT, the Marrakesh Agreement and the World Trade Organization have become reality through the implementation of Trade Related Aspects of Intellectual Property Rights (TRIPS). The challenges that arise for agri-biotechnology have enormous implications because the "Final Round" encompassed investment, intellectual property rights and was extended to include the complex agricultural sector. Developing countries are uncertain whether Intellectual Property Rights (IPR) will promote economic growth, catalyze innovation and attract external investment and technology or whether the reverse will happen. IPR will impact not only on finished products that are imported but also on the management and protection of biodiversity which is a rich but underdeveloped endowment in many developing countries. Organizations such as ISAAA, which have an honest broker role between the generators of proprietary biotechnology products in industrial countries and client developing countries, have a pivotal role to play at this time when it is critical that the challenges that IPR pose are transformed to opportunities that are of mutual benefit to both the generators and the users of agri-biotechnology applications. IPR and licensing are becoming increasingly important in technology transfer and are frequently the principal constraints that limit the transfer and introduction of biotechnology to developing countries even when the technology is generated in the public sector in industrial countries. Accordingly, in 1998 ISAAA will staff a full time senior staff position to assist with the equitable management of proprietary science as it relates to the technology transfer of transgenic crops applications. More specifically the ISAAA initiative in IPR will seek to facilitate the following: provide resources to facilitate biotechnology transfer in ISAAA's current and future portfolio of projects; provide consulting services on IPR to national programs and organizations constrained by IPR issues; develop capacity building in IPR in developing countries so that they gain a better understanding of IPR, and benefit, rather than be constrained, by their adoption.

Another feature of the fast changing crop biotechnology industry, and that impacts on IPR, is that different components of a single piece of technology are often, and increasingly owned by different and competing corporations. For example, the gene itself can be patent-protected by one party, the transformation and regeneration protocol by another and the promoter by yet another; up to seven parties can be involved in the multiple ownership of the different components related to a single trait in one crop. This adds significant complexity to negotiating license agreements that are acceptable to all parties, particularly when the ownership of the components of the technology is often being contested in law suits amongst the same parties. Contested and multiple ownership are becoming increasingly important features of biotechnology that require considerably more effort on the part of developing countries, or technology transfer organizations such as ISAAA, that assist in accessing proprietary technologies from the private sector in industrial countries. However, failure to invest in biotechnology transfer condemns developing countries to dependency on conventional technology whereas they have the greatest need for biotechnology in order to ensure future food security.

Public Perception and Acceptance of Biotechnology

Acknowledging that public acceptance of any product in the market place is affected by both perceptions and fact, it is important to gain a better understanding of the views and concerns of the public in relation to transgenic crops and the use of derived products for food, feed and fiber. Hoban (1997), has recently discussed and published the results of several surveys on this subject (Food Marketing Institute 1995a, 1995b, 1996, Hoban 1996a, 1996b). His findings show that between two-thirds (66 percent) and three-quarters (75 percent) of Americans surveyed are supportive of biotechnology. Hoban reported that 82 % of Japanese consumers were in favor of using biotechnology to develop superior varieties of crops. In Europe, results varied by country; excluding Germany, Austria, Norway and Luxembourg, where acceptance was lowest, Hoban reported that more than half (>50 percent) of people surveyed in Europe were prepared to buy food products that had been modified by biotechnology. Hoban concluded that the differences in acceptance levels amongst countries was by and large related to the knowledge level of respondents vis-a-vis the specific benefits associated with biotechnology. Thus, it is important for the scientific community at large, both public and private sector organizations involved in biotechnology, to support a program that informs the lay public about both the benefits and issues related to biotechnology. There is already evidence from the US to support the view that, given adequate information about biotechnology-improved food and feed products, consumers accept transgenic products. The first significant tonnage of biotechnology improved crops was produced in North America in 1996; consumer-acceptance of these biotechnology derived products was favorable, which regulatory agencies determined to be equivalent to corresponding non-transgenic varieties vis-a-vis nutrition, allergenicity and other regulated characteristics monitored in relation to health and safety standards.

In Europe, public opinion regarding transgenic products has placed more emphasis on the need to provide choice to consumers by labeling transgenic products. Some corporations, who handle food products view the logistical and operational constraints associated with ensuring "identity preservation" between transgenic and non-transgenic products to be unmanageable. It is the judgment of some corporations that "it is technically impossible to produce a product that is more than about 98 % pure" - thus ethically the non-transgenic product label is a claim that they are not in a position to guarantee, and accordingly could be held liable for the consequences. European consumers have also placed emphasis on the issues associated with the use of antibiotic resistance marker genes in genetically modified plants for human food and animal feed. More specifically, the concern has related to the likelihood of transfer of the antibiotic resistance gene markers to microorganisms in the human gut or animal rumen, that could in turn contribute to a further increase in the levels of antibiotic resistance found in natural populations of microorganisms which could compromise clinical and veterinary antibiotic-based therapy treatments. Several national and international scientific/regulatory panels have studied this issue in detail, many of which have determined that the antibiotic markers are appropriate and safe for use. However, concern continues in Europe, particularly public opinion.

In a recent editorial (Carter 1997), former US President Jimmy Carter endorsed the use of biotechnology for achieving global food security and condemned extremist groups in affluent countries who continue to oppose the use of biotechnology. The public acceptance of biotechnology-derived crops and products discussed above all relate to perceptions in industrial developed countries where there is a surplus of food, and availability and widespread hunger are not issues; this is quite different to the situation in most, if not all developing countries. Carter's views concur with those of Suman Sahai, Convenor of the Gene Campaign, from New Delhi, India, who considers that ethical concerns about biotechnology-improved food/feed products are a luxury that only industrial countries can afford (Sahai 1997). He strongly maintains that developing countries, such as India, must utilize biotechnology to address the urgent issue of increasing food production to overcome current suffering from malnutrition, hunger and starvation. Sahai questions whether it is more unethical to "interfere in God's work" than to allow hunger deaths when these can be prevented and counsels that biotechnology be implemented to high safety standards and that "the concerns and debates in each society must be specifically relevant to that society and rooted in its needs and in its culture".

It is evident that biotechnology presents different challenges and offers new opportunities for the 21st century and that these must always be addressed appropriately in industrial and developing countries, recognizing that the respective needs and priorities are often completely different. Thus, developing biotechnology initiatives which are need-based and country specific is important. This will allow countries in both the North and South to make decisions based on their respective national priorities on topics ranging from transfer of finished biotechnology products from North to South, to the utilization of biodiversity from the South in equitable South-North partnerships that will ensure that biotechnology's contribution to agriculture will be sustainable. The 21st century will be a world of inter-dependence, where the different needs of respective countries must be respected and where their corresponding comparative advantages must be maximized in equitable partnerships that result in mutual advantages.

Mergers and Alliances

Biotechnology has been the major catalyst responsible for the consolidation that has taken place in the chemical, pharmaceutical and seed industries in the 1990s. The value of recent mergers and alliances which have consolidated resources in the private sector for biotechnology crop related activities alone, is conservatively estimated at US$ 8 billion (Table 17). The major incentives that have underpinned all the mergers and alliances are the need to create the necessary minimal critical mass for biotechnology R&D, to maximize complementarity of merging partners, and to increase the probability that the new merger or alliance will ensure a competitive global market in the future which, over time, will be dominated by fewer and fewer companies.

The initial mergers that took place at the beginning of the 1990s were driven by the first generation of products which featured agronomic traits, such as delayed or improved ripening technology, insect and disease resistance, herbicide tolerance; these are often referred to as "input-traits" that result in direct benefits to farmers and indirect benefits to consumers. During the latter part of the 1990s "output-traits" which enhance the value of the food and feed end product will become increasingly more important than input-traits. The quality/output-traits will result in improved nutrition in food and/or feed products and provide economic benefits to food processors who will increasingly cater for higher value niche specialty products

Table 17: Recent Agri-Biotechnology Acquisitions, Mergers and Alliances, 1997

Company	**Acquisitions, Mergers and Alliances**	**Estimated value** ($ billion)
Monsanto	Calgene, Agracetus, DeKalb, Delta & Pine Land, Asgrow, Holdens (acquisitions and mergers)	2.0
Pioneer	Dupont (alliance)	1.7
Novartis	Ciba and Sandoz (merger)	1.0
ELM	Asgrow, Petoseed, Royal Sluis, DNAP (acquisitions)	1.0
AgrEvo	PGS, Sun Seeds (acquisitions)	1.0
ADVANTA	ZENECA and van der Have (joint venture)	0.5
DowElanco	Mycogen (46% investment)	0.2
Others		0.6
Estimated total value		**8.0**

Source: Clive James

in response to changing consumer demands. The long term potential value of the market associated with output traits is likely to be significantly greater than the input-trait market; this consideration was probably a major factor catalyzing the latest alliance, valued at US$ 1.7 billion, between Pioneer and DuPont announced in August 1997. The alliance between the two companies to form a joint venture called "Optimum Quality Products" allows Pioneer to enhance the value and market share of its crop germplasm (principally corn where it controls 42 % of the USA market in 1997); it is important to note that more than 80 percent of the world's corn is fed to livestock (Pioneer 1997) and therefore enhancing the nutrition of livestock feed will be a principal objective of the joint venture. Pioneer's germplasm provides DuPont with an effective vehicle for incorporating and delivering its broad-range of output-traits, which are recognized to be its comparative advantage. These output-traits include high-oil corn that offers enhanced nutrition for the feed market and high oleic acid soybean that is attractive to the food processing industry because of its lower costs. Thus the alliance between Pioneer and DuPont is intended to speed the discovery, development and delivery of new crops that will benefit growers, livestock producers, food processing industry and consumers. Food and feed products from these transgenic crops that will contain more amino acids, such as lysine, and modified oils that can be used to make specialty foods with less saturated fats, are expected to be introduced in about two years.

Consolidation is likely to continue, through mergers and alliances although the thrust will probably change from mergers between biotechnology companies to vertical integration of food, feed and industrial products; the increased emphasis on crop genomics will also catalyze new alliances. Similarly, licensing of proprietary technologies between companies, which is already widely practiced, is likely to increase in the future as the companies develop more products and markets in both industrial and developing countries. The commercialization of transgenic crops initiated in 1996 in North America with 4 million acres, which has increased more than a fivefold in USA and Canada in 1997 to 23 million acres has led to a significant increase in patents filed for biotechnology improved crops. Seeds were first declared to be patentable in the US in 1985 and by early 1997 there were more than 1,200 applications for biotechnology improved crop varieties pending at the US Patent Office. This significant increase in crop patents has occurred at a time when more than 70 developing countries have become signatory to the "Trade Related Aspects of Intellectual Property Rights (TRIPS) negotiated under the World trade Organization (WTO). Plant Breeders' Rights (PBRs) is the regulatory vehicle in TRIPS to protect intellectual property rights vis-a-vis improved crop varieties. Despite the fact that PBRs are not currently adopted in developing countries, significant progress is expected with the implementation of PBR guidelines that will provide a measure of intellectual property rights protection by all signatories to TRIPS. Accordingly, most of the advanced developing countries are drafting legislation that will eventually afford more protection for improved crop varieties under plant breeders' rights.

Global Investments and Markets in Biotechnology

Recent data for 1995 on investments, revenues, and R&D expenditures show that there has been a dramatic increase in the decade 1985 to 1995. In the USA alone total sales of new biotechnology-based products in all sectors were $ 9.3 billion in 1995. It is estimated that sales will grow at 12 percent per year to reach $34 billion by the year 2006 (Ernst & Young 1995). More specifically, Table 18 shows that in 1995 sales of agricultural biotechnology products in the USA were $100 million with an R&D expenditure of $2 billion; the corresponding sales for pharmaceutical products in 1995 were $7 billion sales and $8 billion in R&D. In 1996 the U.S. sales of agribiotech products increased to $304 million and this figure is expected to increase by 20 percent per year (Ernst & Young 1996). It is estimated that of the $10.8 billion total sales of biotechnology products in the United States in 1996, human therapeutics represented 75 percent of total sales, human diagnostics 17 percent, agriculture 3 percent, specialties 3 percent, and non-medical diagnostics 2 percent (Ernst & Young 1996, Persley 1997). The global market for agricultural biotechnology is projected at <$ 0.5 billion for 1996, increasing to a value of $ 2 to 3 billion by the year 2000, $ 6 billion by 2005 and $ 20 billion by 2010. Current estimates for 1996 and 1997 confirm that projected markets are being realized, and may indeed exceed the projected value of $ 2 to 3 billion by the year 2000 if high adoption rates continue during the remaining two years of the decade.

Whereas a high proportion of the R&D investments in agri-biotechnology are undertaken by the private sector, various public institutions and organizations that serve domestic and international interests are assigning higher priority to biotechnology. The World Bank has lent $100 million in support of biotechnology, whilst the Rockefeller Foundation and bilateral agencies, including those in the United States, U.K. and the Netherlands, have invested $200 million during the last decade (Brenner 1996). National research agencies such as USDA, BBSRC in the United Kingdom, and CSIRO in Australia, have also made significant investments in biotechnology. The CGIAR international agricultural research centers estimate that biotechnology expenditures are currently $22.4 million per year, of which $10 million is spent on animal biotechnology and the balance of approximately $12 million on crop biotechnology by a total of eight centers (CGIAR 1996).

Table 18: Sales and R&D Expenditures for Biotechnology Products in the United States, 1995 and 1996 ($ millions)

	1995	1996
Pharmaceutical Sales	7,000	8,600
Pharmaceutical R&D	8,000	N/A
Agricultural Sales	100	304
Agricultural R&D	2,000	N/A
Other Sales	2,200	1,896
Total Sales	**9,300**	**10,800**

Source: Compiled by Clive James and derived from Ernst & Young (1995), Ernst & Young (1996), & Wood Mackenzie (1997).

Global Food Security

Global food demand is forecast to at least double, and possibly triple, by the year 2050 when the world population is expected to reach 10 billion people. In order to ensure increased nutrition for a growing population it will be necessary to expand food production faster than population growth. Dietary changes that accompany increased affluence will result in food demand being larger than the projected increase in population. Estimates suggest that China alone will have to triple its grain imports from approximately 15 million tons in 1995 to 45 million tons in the year 2010, and other countries with large populations, such as India, will also become significant net importers of grain. Abiotic stresses due to drought, salinization, waterlogging, toxic levels or deficiencies of nutrients and biotic stresses due to weeds, insects and diseases take a heavy toll of the 5 billion tons of food that is currently produced annually. For example, crop pests alone, for which biotechnology solutions are already available and being commercialized, reduce global food production by at least one-third, equivalent to 1.5 billion tons of food, despite the fact that $32 billion is spent annually on conventional pesticides. A recent report (Kendall et al 1997) by a panel of experts commissioned by the World Bank to assess the potential of crop bioengineering advocated the appropriate use of biotechnology and concluded that "it is likely that efforts to improve the rice yield in Asia through biotechnology will result in a production increase of 10 to 25 percent over the next ten years"; preliminary evidence for

1996 in the USA for crops such as corn and soybean indicate that 10 to 25 percent increases in yield for transgenic crops are feasible and realistic during the next decade.

The principal challenge posed by global food security is whether the world can produce the extra amount of food needed in the future, and what are the options for ensuring that demand does not outstrip supply. Every effort must be made by the global community to reduce food demand by implementing policies that will contribute to lower population growth rates in future. Experience indicates that this is possible through substantive social intervention by Governments, as was the case with China, or where social and educational changes have catalyzed lower population growth rates in the more affluent countries of the North, and in some of the newly industrialized countries of the South. Global and national policy changes are necessary in agriculture that will provide higher rewards for food producers and processors in developing countries; and industrial countries need to open their markets to the food producers from the countries in the South. Increased resources for agricultural research and development are essential so that conventional and biotechnology applications can be accelerated and integrated to produce higher yielding crops and safer foods. It is now widely acknowledged that conventional technology alone will not allow food production to be doubled and biotechnology will be an essential and increasingly important component of a global food security strategy. The data presented in this manuscript provide early indications that the 7 million acres (2.8 million ha) grown in 1996 and the 31.5 million acres (2.8 million ha) of commercialized transgenic crops grown in 1997 have resulted in significant benefits, and that early promises of biotechnology can be met in terms of increased productivity and in environmental benefits. Most of the investments in biotechnology have been made by the private sector and there is an urgent need to build new partnerships between the global public and private sectors in agricultural research to maximize the use of global limited resources assigned to agricultural research and to optimize the comparative advantages of the respective partners for the global benefit of society. Tomorrow’s world will be more of a global village where interdependence will be a prerequisite to success and survival, where the North and the South and the public and private sectors will need to work together towards the critically important goal of global food security.

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Appendix

Table 1A: List of 60 Transgenic Crops in Field Experiments Worldwide 1986 to 1997

Large No. of field trials (commercialized)	**Medium No. of field trials (pre-commercial)**	**Low No. of field trials (experimental)**	
>150 trials	**25-150 trials**	**1-25 trials**	
Canola/napus	Alfalfa	*Amelanchier laevis*	Grape
Canola/rapa	Cantaloupe	Apple	Kiwi
Cotton	Carnations	*Arabidopis thaliana*	Lettuce
Maize corn	Flax	Asparagus	Lupins
Melon	Rice	Barley	Mustard, brown
Potato	Squash	Belladonna	Mustard, Indian
Soybean	Sugarbeet	Birch	papaya
Tobacco	Sunflower	Blueberry	Pea
Tomato		Broccoli	Peanut
		Cabbage	Pepper
		Carrot	Petunia
		Cauliflower	Plum
		Chicory	Poplar
		Chrysanthemum	Raspberry
		Clover	Serviceberry
		Cranberry	Spruce
		Creeping bent grass	Strawberry
		Cucumber	Sugarcane
		Eggplant	Sweetpotato
		Eucalyptus	Walnut
		Gerbera	Wheat
		Gladiolus	

Source: Extended from James and Krattiger (1996).

US$ 10.00