9. Bt COTTON

9.1 Introduction

This chapter is devoted to assessing the performance of Bt cotton to-date and to assess the future global potential for Bt cotton, or cotton with other novel genes, that confer resistance to the major caterpillar/moths (lepidoptera). These insect pests are of significant economic importance in cotton producing countries around the world. Bt cotton was first adopted commercially six years ago in 1996. In 2002 it was deployed commercially in nine countries, seven of which were developing countries (China, India, Indonesia, Argentina, Mexico, South Africa, and Colombia [pre-commercial]), and two industrial countries (USA and Australia). There is now considerable published experimental and survey data of commercial Bt crops generated from independent studies to assess the impact of Bt cotton to-date. These studies have documented the production, environment, health, economic, and social impact of Bt cotton in both large and small farms in developing and industrial countries.

The content of this chapter is structured chronologically to provide the reader with a global overview of the cotton crop, present available data for assessing the performance of Bt cotton to-date and project its future global potential. The focus on developing countries is consistent with ISAAA's mission to assist developing countries in assessing the potential of new technologies. The principal aim is to present a consolidated set of data that will facilitate a knowledge-based discussion of the potential benefits that Bt cotton offers global society. The topics presented in this chapter are:

- The cotton crop
- Global distribution of cotton in developing and industrial countries, by area, production, consumption, imports, and exports
- Number of cotton farmers worldwide and size of farms
- Insect pests of cotton
- Crop losses due to insect pests of cotton and the cost of control
- Global insecticide usage on cotton
- The use of Bt genes in cotton
- Assessment of environmental risk and Insect Research Management (IRM) strategies
- Global adoption of Bt cotton
- Eight Bt cotton country case studies – USA, Australia, China, India, Mexico, Argentina, South Africa, and Indonesia
- Global assessment of the Bt cotton experience to-date: agronomic, environmental social, and economic benefits

- Future global potential for Bt cotton: opportunities and challenges.

9.2 The Cotton Crop

Cotton is the world's principal fiber, used in almost half of all textiles (Rabobank, 1996). The cultivation of the cotton crop has impacted on the economic development of countries since it was first cultivated, 5,000 to 10,000 years ago (Stephens and Mosley, 1974). Cotton was not known in Europe until the late Middle Ages. However, during the Industrial Revolution in Western Europe it played an important role; large scale processing made it the world's main clothing fiber by the end of the 19th century when cotton comprised 80 % of all textile material. Today, whereas cotton still retains its status as the most valuable and preferred natural fiber, man-made synthetic fibers have eroded cotton's share in textiles to around 40 %. About 20 million tons of raw cotton valued at about $ 20 billion is now produced annually, 30 % of which is traded as raw material. In 2000/01 cotton prices were at historical lows of $ 0.40 per pound and the level of direct assistance provided by governments in 2000/01 was approximately $ 4 billion. Trade in cotton related products represents almost half of the total $ 115 billion trade in textiles and the $ 133 billion trade in clothing (Rabobank 1996).

Cotton is grown in the hotter regions of approximately 65 tropical/subtropical and temperate countries around the world. Whereas cotton is intrinsically a hot weather crop and performs optimally in the tropics and subtropics, varieties have been developed that perform well and are well adapted to the warmer temperate areas of cotton-growing countries. Cotton is grown on many soil types, ranging from sandy to clays but prefers a heavy loam. Cotton is one of the most efficient crops in terms of water utilization in that it produces one of the highest quantities of dry matter per liter of water. Duration from planting to harvest ranges from 140 to 250 days (Hearn and Fitt 1992); it is possible to grow cotton in regions where the frost-free period is less than 180 days. The timing of planting and harvesting of cotton operations differ in the Northern and Southern Hemisphere and are listed below for some of the major cotton-growing countries. Brazil is divided into two regions in terms of cotton production. In southern Brazil there is a high input intensive cotton production system and in the north a low input system featuring perennial cotton.

	Planting	Harvesting
Northern Hemisphere		
USA	Feb-May	Sep-Nov
China	Apr-June	Sep-Oct
CIS*	Apr-May	Sep-Nov
Turkey	Apr-May	Sep-Nov
Greece	Apr-May	Sep-Nov
India	Apr-June	Oct-Feb
Southern Hemisphere		
Brazil (North)	Feb-Aug	Aug-Feb
Brazil (South)	Oct-Nov	Feb-Jun
Argentina	Sep-Oct	Feb-May
Australia	Sep-Oct	Apr-Jul

Source: Modified from Rabobank, 1996.
* CIS – Commonwealth of Independent States

Water requirements for cotton are critical – ideally it prefers an early wet period to promote vegetative growth followed by a dry season during which the flowers and fruits mature and dry. Irrigation is often used to optimize availability of water. Cotton requires abundant sunshine and an optimal average growing temperature in the range of 25°C to 30°C. Cotton production can be labor or capital intensive, with the former normally applying to developing countries where labor cost is low and capital limited, whereas the reverse is normally the case for industrial countries.

Cotton is a member of the genus *Gossypium* and belongs to the *Malvaceae* family which also includes the flowering shrub Hibiscus and Okra. More than 95 % of commercial cotton is upland cotton, *Gossypium hirsutum,* while long staple cotton, *G. barbadense*, occupies a small area of <5%. Both cultivated cotton species are self pollinating allotetraploids, are incompatible with the diploid wild species of cotton, and there are no identified non-cotton wild relatives with which upland and long staple cotton will outcross. Two species of Asiatic cotton, *G. arboretum* and *G. herbaceum* are grown in restricted areas of Asia and Africa; these are diploid and incompatible with upland and long staple cotton.

Upland cotton and long staple cotton are both perennial dicots, but they are normally cultivated as an annual crop. With few exceptions, the commercial seeds that are sold globally to farmers are varieties rather than hybrids: India is an exception where approximately 50% of cotton is hybrid.

Cotton is grown principally for the fiber although a small quantity of the seed is used as a source of food, feed and oil for humans and animals. Cotton seed oil is refined before it is used for human consumption to remove Gossypol which is toxic to humans and monogastric animals. The fruit of the cotton plant is more familiarly known as the boll, which contains approximately ten cotton seeds that are surrounded by the fibers (lint) which grow from the coats of the seed. The cotton lint is the primary commercial product that generates income for cotton producers and lint yield is approximately one-third by weight of seed cotton which is the product harvested by farmers. The lint is separated from the seed during processing at a ginnery. Given that cotton is self pollinating, farmers can save seeds for planting. However, subsequent to the ginning process there are small fibers (linters) still attached to the seed which require further processing (delinting) before they can be used as high quality seed for optimal production of cotton, so in practice it pays farmers to buy new seed annually. World production of lint has more than doubled from 9.8 million tons in 1960/61 to 21.2 million tons in 2001/02. Lint yield has also more than doubled from 305 kg/hectare to 635 kg/hectare over the last 20 years while the area of cotton has remained approximately the same. Yields in Latin America and Africa have improved fairly slowly during the last 20 years whereas significant gains have been made in selected countries such as China in Asia.

9.3 Global Distribution, Production, Consumption, Imports and Exports

Of the 33.5 million hectares of cotton grown in 2001/2002 approximately 70% were planted in developing countries and only 30 % in industrial countries. The top 10 cotton countries, by area, (listed in Table 22) accounted for 80 % of the planted area of global cotton, with the balance of 20 % grown in the other 55 countries. Of the top 5 countries that planted more than 1 million hectares each (for a total of 23.5 million or 70 % of global total), India has by far the largest area (8.7 million hectares), followed by the USA (5.6 million hectares), China (4.8 million hectares) Pakistan (3.1 million hectares), and Uzbekistan (1.5 million hectares). It is noteworthy that of the 70 % of global cotton planted in countries of the South, three Asian countries predominate, India, China and Pakistan, that together plant 50 % of global cotton. Six out of the ten top cotton-growing countries, by area, are from the South, three from Asia (India, China and Pakistan), two from Africa (Mali and Benin), and Brazil in Latin America. The other four countries comprise USA, with the second largest area (5.6 million hectares), the two Commonwealth of Independent States (CIS) states of Uzbekistan (1.5 million hectares) and Turkmenistan (0.6 million hectares), and Turkey (0.6 million hectares) in Western Asia.

Table 22. Top 10 Cotton-Growing Countries by Area, 2001-2002

Country	000 Ha	
1. India	8,730	
2. USA	5,596	
3. China	4,824	
4. Pakistan	3,125	
5. Uzbekistan	1,453	
6. Brazil	750	
7. Turkey	654	
8. Turkmenistan	550	
9. Mali	516	
10. Benin	415	
Subtotal	**26,613**	(80%)
Others	**6,844**	
World Total	**33,457**	

Source: ICAC, 2002a.

Global production of cotton (lint) has increased from 9.8 million tons in 1960/61 to 21.2 million tons in 2001/02 – an increase of 116 % over the last 40 years. The top 10 cotton countries, in terms of total production in 2001are listed in Table 23, along with corresponding yield data. Collectively they produce 85 % of global cotton production. As for the previous data, based on cotton area, six of the top 10 cotton producing countries are developing countries, China (5.3 million metric tons (MT)), India (2.5 million MT) Pakistan (1.8 million MT), Brazil (0.7. million MT), Syria (0.3 million MT) and Egypt (0.3 million MT).

China with a high yield of 1,103 kg of lint per hectare is the top lint producer globally with a production of 5.3 million tons followed by the US (4.4 million MT). Both India and Pakistan

Table 23. Top 10 Producers of Lint Cotton in 2001-2002

Country	000 Metric Tons		Lint Yield Kg/Ha
1. China	5,320		1,103
2. USA	4,420		790
3. India	2,508		287
4. Pakistan	1,853		593
5. Uzbekistan	1,055		726
6. Turkey	880		1,345
7. Brazil	750		999
8. Australia	670		1,658
9. Syria	335		1,303
10. Egypt	314		994
Subtotal	**18,105**	**(85%)**	**980**
Others	**3,132**		
World Total/Average	**21,237**		**635**

Source: ICAC, 2002a.

have significantly lower production than China. Despite having large areas of cotton, they suffer from low yields, 287 kg/hectare and 593 kg/hectare respectively, whereas Syria, Egypt and Brazil have significantly higher yields of 1,303 kg/hectare, 994 kg/hectare and 999 kg/ hectare respectively. Australia has by far the highest world yield of lint at 1,658 kg/hectare followed by Syria (1,303 kg/hectare) and China (1,103 kg/hectare) (ICAC 2002a). Thus, in general, developing countries like China, with a large area of cotton and high yields excel in terms of total production, whereas countries like India and Pakistan with large areas suffer in terms of total production because of low yields. India has the lowest yield of the top 10 producers at 287 kg/hectare, which is less than half of the world average yield of 635 kg/ hectare. Brazil, Syria and Egypt compete well in terms of total production because of high yields, whereas African countries such as Mali and Benin which grow approximately 500,000 hectares of cotton do not excel in total production because of low yields of 464 and 420 kg/hectare, respectively. In summary, the major constraint to increased production in many developing countries is low productivity, due to abiotic, biotic and other constraints, with insect pests, particularly lepidopteran pests, featuring as a prevalent and significant constraint in all developing countries.

Global consumption of cotton in 2001 was approximately 19.9 million metric tons; this compares with production of 21.2 million metric tons. It is noteworthy that China, India and Pakistan are the top 3 consumers of cotton, totaling 9.1 million metric tons, close to half of the global production of 21.2 million MT. Of the top 10 countries that consume 78% of global cotton, (Table 24) 7 are developing countries. Listed in descending order of importance, they are China (5.4 million MT), India (2.9 million MT), Pakistan (1.8 million MT), Brazil (0.9 million MT), Indonesia (0.5 million MT), Mexico (0.4 million MT) and Thailand (0.4 million MT); these 7 countries consume approximately 60 % of world cotton production - four are Asian, two are from Latin America, and Africa is conspicuous by its absence. USA (1.7 million MT), Turkey (1.3 million MT) and Russia (0.4 million MT) are the other three significant consumers of cotton.

Many of the developing countries that are large consumers of cotton are also significant importers of cotton (Table 25). These include Indonesia, India, Thailand, Mexico and Pakistan. Large consumer developing countries that rely only on limited imports include China (imports of 100,000 MT) and Brazil (150,000 MT).

Table 24. Top 10 Consumers of Lint Cotton in 2001-2002

Country	000 Metric Tons	
1. China	5,400	
2. India	2,856	
3. Pakistan	1,830	
4. USA	1,655	
5. Turkey	1,250	
6. Brazil	860	
7. Indonesia	525	
8. Mexico	403	
9. Thailand	371	
10. Russia	364	
Subtotal	**15,514**	(78%)
Others	**4,422**	
World Total	**19,936**	

Source: ICAC, 2002a.

Table 25. Top 10 Importers of Cotton 2001-2002

Country	000 Metric Tons	
1. Indonesia	550	
2. Turkey	500	
3. India	450	
4. Russia	390	
5. Thailand	387	
6. Mexico	383	
7. Republic of Korea	331	
8. Italy	285	
9. Taiwan	280	
10. Pakistan	275	
Subtotal	**3,831**	(60%)
Others	**2,535**	
World Total	**6,366**	

Source: ICAC, 2002a.

The top 10 exporters of cotton are listed in Table 26 with the USA by far the largest exporter (2,389,000 MT, equivalent to 38% of world exports), followed by Uzbekistan (729,000 MT), Australia (700,000 MT), Greece (257,000 MT) and Syria (187,000 MT). It is noteworthy that 4 out of the top 10 exporters are countries from West Africa, i.e. Mali, Benin, Cote d'Ivoire and Burkina Faso. These Francophone countries in Africa have suffered a great deal from low cotton prices in recent years, and are among the poorest in the world. Losses due to cotton insect pests and high expenditures on insecticides exacerbate the problems of low prices for exports, particularly as cotton exports in several of these countries represent 50 % or more of their total export earnings. In the event that Bt cotton could lower cost of production and increase productivity and income, this would be a significant advantage to the national economies of these countries.

In summary, taking into account the global distribution of cotton by area, production, consumption, imports and exports, it is evident that developing countries are major players in all aspects related to cotton and thus potentially stand to gain from any technology that will decrease cost of production, and simultaneously increase productivity and income. In addition, significant advantages in terms of the environment, health and social benefits can accrue if pest infestations that can

Table 26. Top 10 Exporters of Lint Cotton 2001-2002

Country	000 Metric Tons	
1. USA	2,389	
2. Uzbekistan	729	
3. Australia	700	
4. Greece	257	
5. Syria	187	
6. Mali	181	
7. Benin	139	
8. Cote d'Ivoire	133	
9. Burkina Faso	126	
10. Turkmenistan	125	
Subtotal	**4,966**	(78%)
Others	**1,400**	
World Total	**6,366**	

Source: ICAC, 2002a.

be controlled by Bt are a significant constraint to increased productivity. Developing countries that have already deployed Bt cotton and are deriving significant benefits include China, India, Indonesia, Argentina, Mexico, and South Africa.

9.4. Number of Cotton Farmers Worldwide and Size of Farms

Documented statistics re the number of cotton farmers are not available for most cotton-growing countries and hence the data in Table 27 are based on estimates for some countries. The number of cotton farmers for developing countries may be conservative for some countries where farms are registered in the official records as one farm by landowners, but in practice are actually fragmented and farmed by many tenant farmers. This can lead to a significant under-estimate of the number of cotton farmers, and an over- estimate of the average size of cotton holdings. Therefore, the data in Table 27 is intended only as a guide as to the order of magnitude of the number and size of farms, rather than precise estimates. The number of farmers in China alone can vary from 9 to 13 million depending on the area planted to Bt cotton (Huang 2002); the average of 11 million is used for the number of cotton farmers in China in Table 27. It is estimated that there are approximately 20 million cotton farmers worldwide (Table 27), of which about 97% (19.3 million) farm in the developing countries of Asia, Africa and Latin America, and 2% (425,000) in the CIS and West Asia countries. Less than 1% of cotton farmers worldwide grow cotton in the industrial countries; the US has approximately 30,000 cotton farmers, Australia 1,200, with the balance in Greece and Spain.

Of the 19.3 million cotton farmers that grow cotton in the developing world about 89% (17.1 million) farm in the developing countries of Asia, 2.5 million in Africa (10% of cotton farmers globally) and about 150,000 farmers (<1%) in Latin America. The three countries of China, India and Pakistan alone represent 16.5 million cotton farmers or 83% of all cotton farmers globally. A very high percentage (>90%) of cotton farmers in developing countries farm about 2 hectares of cotton or less, with farmers in north and east China growing, on average, less than 0.5 hectare of cotton. Average cotton holdings per farm in India and Pakistan are approximately 2 hectares, while Africa and South East Asia are also about 2 hectares or less; however, in practice, the cotton holdings may be significantly smaller in size because of record misrepresentations. By and large, cotton farms in developing countries are small, and a high proportion are farmed by resource-poor farmers. Average cotton holdings are larger in Latin America (8 hectares) due to bigger farms in countries such as Argentina. Average cotton holding in the US is approximately 190 hectares and 330 hectares for Australia.

Thus, of the 20 million cotton farmers worldwide, most (97 %, over 19 million) are small farmers in developing countries growing about 2 hectares or less cotton. In terms of number of potential beneficiaries from Bt cotton, it is clear that small resource-poor farmers in developing countries are the significant practitioners in cotton production globally; consequently they stand to gain the most from Bt cotton if they can have access to the technology. Currently, from 4 to 5 million small farmers grow small to modest areas of cotton in about 30 developing countries which have not adopted Bt cotton and hence farmers do not have access to a vital competitive technology that could provide them with significant environmental, economic, health and social benefits. Cotton is often the only cash crop for resource-poor cotton farmers and a crop failure because of insect pests can have a disastrous effect on their livelihoods. Cotton is also the principal export of many of the cotton-growing developing countries and production failures due to the major lepidopteran insect pests, for which Bt cotton confers protection, can have a devastating effect on national economies which are already carrying horrendous debts and are suffering in the current global economic recession.

9.5 Insect Pests of Cotton

Insect pests of cotton are a major constraint to production because of the significant yield losses and quality degradation they cause. However, infestation levels of specific pests

Table 27. Estimate of Number of Cotton Farmers Worldwide and Size of Cotton Holdings, 2001

Country	Cotton Farmers (Millions)	Cotton Area (Million Hectares)	Average Cotton Holding per Farm
China	11.000[1]	4.8	0.4
India	4.000[2]	8.7	2.2
Africa	2.500*	4.3	1.7
Pakistan	1.500*	3.1	2.1
West Asia[3]	0.125*	1.0	8.0
CIS[4]	0.300*	2.5	8.3
South East Asia	0.250*	0.5	2.0
Latin America	0.150*	1.2	8.0
USA	0.030[5]	5.6	187.0
Australia	0.001[5]	0.4	330.0
Others	0.219*	1.3	5.9
Total	**20.075**	**33.4**	

Source: Compiled by Clive James, 2002, from various sources including ICAC, 1999.
[1]Number of farmers can vary from 9 to 13 million (Huang 2002). Personal communication. [2]Ag. Statistics Division, Dept. of Agriculture, India 2000. [3]Turkey, Syria and Iran. [4]Commonwealth of Independent States, Uzbekistan, et al. [5]Industry estimate. *Estimate. Note that average cotton holdings are based on actual number of farmers which is rounded off to nearest 1000 in the Table.

vary enormously from year to year, from country to country, and from region to region (Benedict & Altman 2001). Although up to 1,326 species of insects have been reported on cotton worldwide (Matthews 1994), the number of insect pests that are economically important are few. Most of the major insect pests of cotton belong to the caterpillar species (*Lepidoptera*) which are listed in Table 28. The information in Table 28 indicates the number of countries where control measures are required for specific pests as well as identifying the most important pests in 10 major cotton-growing countries (Benedict and Altman 2001).

For the purpose of this review, which is to assess the performance of Bt cotton to-date and to assess its future global potential, the following are the most important lepidopteran insect pests: pink bollworm (*Pectinophora gossypiella*), that requires

Table 28. Principal Lepidopteran Pests in the Major Cotton-Producing Countries of the World

Common Name	Scientific Name	# Countries requiring control	Most injurious insect pests in major cotton producing countries									
			USA	Mexico	Brazil	Egypt	Turkey	CIS[1]	Pakistan	India	China	Australia
American bollworm	*Helicoverpa armigera*	24					X	X	X	X	X	X
Australian budworm	*Helicoverpa punctigera*	1										X
Bollworm	*Helicoverpa zea*	7	X	X								
Cutworms	*Agrotis* spp. and others	16	X					X				
Egyptian cotton leafworm	*Spodoptera literoralis*	6				X						
Pink bollworm	*Pectinophora gossypiella*	26	X	X	X	X	X		X	X	X	X
Spiny bollworm	*Earias* spp.	19					X		X	X		
Tobacco budworm	*Heliothis virescens*	4	X	X	X							

Source: Modified from Benedict and Altman, 2001. Data reproduced with permission of authors, J.H. Benedict and D.W. Altman from the chapter 'Commercialization of Transgenic Cotton Expressing Insecticidal Crystal Protein' pp. 137-201 in J.J. Jenkins and S. Saha (ed) Genetic Improvement of Cotton: Emerging Technologies. Published by Science Publications, Enfield, N.H., USA.

1 Commonwealth of Independent States, Uzbekistan and other Central Asian States

control in at least 26 countries, American bollworm (*Helicoverpa armigera*) requires control in 24 countries, spiny bollworm (*Earias* spp.) in 19 countries, cutworms (*Agrotis* spp.) in 16 countries, bollworm (*Helicoverpa zea*) in 7 countries, Egyptian cotton leaf worm (*Spodoptera literoralis*) requiring control in 6 countries, tobacco budworm (*Heliothis virescens*) requiring control in 4 countries, and Australian budworm (*Helicoverpa punctigera*) found only in Australia. Not included in the list but also important in several countries are armyworms (*Spodoptera* spp.) plus some other lepidopteran pests such as *Diaporopsis* spp. and *Alabama argillacea* that are generally of secondary importance on a global scale but can be important in some regions or years. In the Americas, boll weevil (*Anthonomus grandis*) is an important pest in selected countries, but is currently being eradicated in the US. During the last 20 years in the United States the bollworm/budworm complex has been by far the most important insect complex to damage cotton, and on a global basis the complex of various bollworms are also the most important.

Table 29 lists the 33 countries, in descending order of cotton hectarage that grew more than 100,000 hectares of cotton in 2001/02 and identifies the insect pests that can be economically important in the respective countries. The American bollworm, also called cotton bollworm (*Helicoverpa armigera*) is the most prevalent, found in 30 of the 33 countries, equivalent to a 90% incidence. It is followed by pink bollworm in 82% of the countries; other bollworms including *Earias* and *Diparopsis* spp.are found in 63 % of countries, armyworm (*Spodoptera* spp.) in 33% and tobacco budworm in 21% of countries. It is evident that American bollworm, pink bollworm and other bollworms such as the spiny bollworm in conjunction with *Heliothis* are of major significance and are known to cause very severe damage and crop losses globally. These lepidopteran arthropod pests feed on various crops and they migrate from one crop to another. High infestations of these insect pests can lead to very heavy losses and hence biological, cultural and chemical control with insecticides have been used to attempt control. For example, in Uzbekistan, the wasp *Trichogramma* is widely used as a biological control agent, but globally insecticide sprays remain the major control method. The data in Table 29 show that all 33 countries apply insecticide sprays, ranging from an average of 2 to 12 applications per annum. However, in many countries such as China and India, the maximum number of insecticide sprays in some regions of the countries where infestation is heavy, can be up to 30 insecticide sprays per season.

The sequence of events leading to insecticide application is triggered when the infestation level exceeds the economic threshold. Broad spectrum insecticides not only decrease the population of natural enemies, but often result in the insect pest becoming resistant to the insecticide. This leads to more ineffective applications of the insecticide

Table 29. Global List of 33 Countries with >100,000 Ha. in 2001, Listing Major Insect Pests and Average Number of Insecticide Sprays/Season

Country	Area 000 ha	Cotton[1] Bollworms	Pink[2] Bollworm	Other[3] Bollworms	Tobacco[4] Budworm	Army-worms[5]	# Insecticide Sprays[6]
India	8,730	X	X	X		X	6-12
USA	5,596	X*	X		X	X	2
China	4,824	X	X				8-12
Pakistan	3,125	X	X	X		X	6
Uzbekistan	1,453	X	X	X			2-3
Brazil	750		X		X	X	8
Turkey	654	X	X	X		X	4
Turkmenistan	550	X	X				2-3
Mali	516	X		X		X	5
Benin	415	X	X				6
Australia	404	X		X			10
Nigeria	403	X	X				3-4
Tanzania	392	X	X	X			2
Greece	381		X				4
Zimbabwe	364	X	X	X			4
Burkina Faso	351	X	X	X			7-8
Egypt	315		X			X	6-8
Chad	312	X		X			5
Cote d'Ivoire	285	X	X	X			6
Myanmar	270	X	X	X			4
Tajikistan	258	X		X			3
Syria	257	X		X		X	2
Mozambique	213	X	X	X			4-5
Iran	206	X		X	X	X	4-5
Cameroon	202	X	X	X	X		5
Uganda	200	X	X	X			2
Kazakhstan	184	X		X			2-3
Togo	165	X	X	X			3
Argentina	152	X	X		X	X	4
Paraguay	150	X	X		X	X	7
Zambia	125	X	X	X			5
Sudan	123	X					5-6
Peru	102	X	X		X	X	4-5
Others	1,029						
World	**33,457**						

Source: ICAC, 2002 Personal Communication supplemented by other sources. X signifies that insect can be present as major pest: [1]*Helicoverpa armigera* **H. zea* in the US [2]*Pectinophora gossypiela* [3]*Earias* and *Diparopsis* spp. [4]*Heliothis virescens* and other spp. [5]Armyworm and other *Spodoptora* spp. [6]Average no. of sprays/season where maximum and minimum number can deviate significantly.

until eventually cost considerations lead to the abandonment of cotton cultivation, or a switch to alternative insecticides when this cycle, termed ‘pesticide syndrome’, is repeated (Doutt and Smith 1971, Benedict and Altman 2001). Insecticide-induced pest infestations, which in the past have caused catastrophic crop losses, have led to the general adoption of integrated pest management (IPM) which has had varying degrees of success on a global basis; insecticides, worth $1.7 billion on cotton globally in 2001, remain the principal method of control of insect cotton pests. The adoption of Bt cotton in the USA in 1996 and by China in 1997 represented a new concept of control and is an important element of IPM.

The data in Table 30 provides a global overview and summary of the relative levels of infestation (low, medium, medium to high, and high) of lepidopteran pests in the top 50 cotton-growing countries. The respective hectarage of cotton for each country is also listed in descending order. Nineteen of the 50 countries (38%) are in Category 1 where >70% of the national cotton area is infested by lepidopteran pests. Category 1 has 10 Asian countries, including those that grow a large hectarage of cotton, India, China, Pakistan and Australia, which account for 50% of the world cotton area of approximately 33.5 million hectares. Seven countries from the Americas are also included in Category 1 along with Egypt from the African continent and Spain from Europe. The total cotton area of the countries in Category 1 is 18.4 million hectares, equivalent to 55% of the 33.5 million hectares grown globally. Seven of the nine countries that have already commercialized Bt cotton are in Category 1; the only two exceptions are South Africa which is in Category 2 with medium to high infestation, and the USA in Category 3 with medium infestation. Field trials of Bt cotton have been conducted in an additional two countries in Category 1, Spain and Bolivia, bringing the total number of countries that have adopted or field-trialed Bt cotton to 9 out of 19 countries in Category 1, or almost 50%.

In Category 2, the medium to high infestations, there are 21 African countries from all regions of the continent; they include countries from the west, east, central and southern Africa. The total area of cotton in the 21 African countries is 4.3 million hectares, equivalent to 13% of global cotton area. South Africa is the only country in this medium to high infestation category which has adopted Bt cotton. Field trials of Bt cotton have been conducted in Zimbabwe.

Category 3, with medium infestation, covering 31 to 70% of the national cotton area, contains only two countries, the USA and Brazil. The US adopted Bt cotton in 1996, and Brazil has conducted field trials of Bt cotton. The total area of cotton in these two countries with medium infestation is 6.3 million hectares, equivalent to 19% of the global area of cotton.

Category 4, with the lowest level of infestation (up to 30% of national cotton area

Table 30. Lepidopteran Pest Infestation Levels and Cotton Area (000s of Hectares) in the Top 50 Cotton-Growing Countries

Pest Infestation Level H, MH, M, L	Asia		Americas		Africa		Europe		Total No. of Countries
CATEGORY 1	HIGH		HIGH		HIGH		HIGH		
	India	(8,730)	Argentina	(152)	Egypt	(315)	Spain	(88)	**19**
	China	(4,824)	Paraguay	(150)					**(38%)**
	Pakistan	(3,125)	Peru	(102)					
	Australia	(404)	Mexico	(80)					
	Myanmar	(270)	Colombia	(41)					
	Thailand	(49)	Bolivia	(15)					
	Vietnam	(30)	Ecuador	(5)					
	Indonesia	(22)							
	Bangladesh	(17)							
	Philippines	(3)							
CATEGORY 2					MEDIUM TO HIGH				
					Mali	(516)			**21**
					Benin	(415)			**(42%)**
					Nigeria	(403)			
					Tanzania	(392)			
					Zimbabwe	(364)			
					Burkina Faso	(351)			
					Chad	(312)			
					Cote d'Ivoire	(285)			
					Mozambique	(213)			
					Cameroon	(202)			
					Uganda	(200)			
					Togo	(165)			
					Zambia	(125)			
					Sudan	(123)			
					Ethiopia	(45)			
					South Africa	(44)			
					Ghana	(34)			
					Senegal	(33)			
					Kenya	(30)			
					Guinea	(30)			
					Madagascar	(29)			
CATEGORY 3			MEDIUM						
			USA	(5,596)					**2**
			Brazil	(750)					**(4%)**
CATEGORY 4	LOW						LOW		
	Uzbekistan	(1,453)					Greece	(381)	**8**
	Turkey	(654)							**(16%)**
	Turkmenistan	(550)							
	Tajikistan	(258)							
	Syria	(257)							
	Iran	(206)							
	Kazakhstan	(184)							
TOTALS Nos. of Countries & %	17	34%	9	18%	22	44%	2	4%	50 (100%)

Source: Clive James, 2002. Estimates of infestation consolidated from various sources. **L** represents Low infestations of Lepidopteran pests up to 30% of national cotton area affected. **M** represents Medium infestations of Lepidopteran pests between 31 and 70% of national cotton area affected. **MH** represents Medium to High infestations of Lepidopteran pests. **H** represents High infestations of Lepidopteran pests over 70% of national cotton area affected.

infested with lepidopteran pests), has only eight countries out of the total of 50. These include the four Central Asian States of Uzbekistan et al, Turkey, Iran, Syria in West Asia, and Greece. None of the countries in this low infestation category have adopted Bt cotton but it has been field-trialed in Turkey and Greece. The total area of cotton in these eight countries with low infestation is 3.9 million hectares, equivalent to only 12% of the global cotton area.

In summary, 55% of the global cotton area is highly infested with lepidopteran pests (> 70% cotton area infected), 13% has medium to high infestations, 20% of the global area has a medium level of infestation (31 to 70% infestation), with only 12% of global cotton area in the low category with less than 30% of the national cotton area infested. Thus, 88% of the global cotton area, equivalent to 29 million hectares has lepidopteran infestations at medium to high levels, (31% to >70% area infested) where Bt cotton is likely to confer significant benefits over conventional cotton.

9.6 Crop Losses and Cost of Control

Insect pests are recognized to cause significant crop losses and to be a major constraint to cotton productivity throughout the world. In the absence of any control measures (resistant varieties, insecticides, cultural control, IPM), potential losses due to cotton insect pests on a global basis would be in the range of 35 to 41% (Oerke 2002). The actual losses that currently occur, despite control measures in place, are estimated to range from 7 % to 24 % (Table 31**).** Crop losses are correlated to the level of infestation, which will vary by year, by country, by crop variety. The data in Table 31 show the range of actual and potential crop losses for different global regions. These data are general global estimates, and are useful in exhibiting differences in order of magnitude and patterns of loss for different regions.

The data indicate that average potential crop losses globally due to cotton insect pests, in the absence of any control measures, would be of the order of 37 % with no significant differences between global regions; this compares with an average actual loss of about 21 to 22%, suggesting current controls save about 15% of yield. Whereas there are no significant differences between regions for potential losses, there is a substantial difference between continents and regions in terms of actual losses. The highest actual losses occur in Africa in the range of 20%, followed by Asia at about 13 %, the Americas at 11%, and the CIS, Europe and Oceania at 11%, 9% and 7% respectively. The general pattern of actual losses indicates that in the more tropical developing countries, losses are generally higher than in the more temperate regions of developing and industrial countries.

The estimate of actual losses due to cotton insects by Oerke (2002) for North America, which includes the USA and Mexico, is 11%.

Table 31. Range of Actual and Potential Losses from Cotton Insect Pests for Different Global Regions

	Actual Loss % With Controls	Potential Loss % Without Controls
AFRICA		
Eastern	24	35
Western	23	34
Southern	21	37
North	9	41
ASIA		
South East	18	33
South	17	36
East	9	37
North East	9	38
AMERICAS		
South America	13	39
Andean	13	39
North America	11	38
Central	7	37
CIS	11	37
EUROPE	9	35
OCEANIA	7	38

Source: Oerke, 2002 in CABI Crop Protection Compendium, 2002.

Detailed estimates of losses due to insect cotton pests in the US have been compiled since 1979 by cotton entomologists for the US cotton belt (Williams 2002a, 2002b, 2001, 2000, 1999, 1998, 1997, 1996 www.mmstate.edu/Entomology/Cotton). The average loss reported for the 18 year period 1979 to 1996 was 7.5% (Williams 1997b), with the bollworm/budworm complex reported to be the most important pest in 13 out of the 18 years. For the period 1994 to 2001, cotton insect losses in the US have ranged from 4.5% to 11.1% (Table 32) with the value of loss/hectare ranging from $ 65/ hectare to $ 145/hectare with an average of approximately $ 100 per hectare; this translates to an annual loss of approximately $ 500 million at the national level in the US.

In addition to the $ value of crop loss, the US data in Table ll also includes the cost of control, the major portion of which is insecticides and their application. During the period 1994 to 2001 control cost ranged from

Table 32. Losses Due to Cotton Insect Pests in the US and Cost of Control by Insecticides and Other Means, 1994 to 2001

	Yield Loss %	Yield Loss $/Ha	Control Costs $/Ha	Loss + Control $/Ha	Value of Loss and Control (National US)
1994	6.0	65	123	187	$1.0 billion
1995	11.1	140	145	285	$1.7 billion
1996	6.6	110	113	225	$1.2 billion
1997	9.4	145	133	278	$1.5 billion
1998	8.0	128	158	286	$1.2 billion
1999	7.7	108	125	233	$1.3 billion
2000	9.3	138	155	293	$1.7 billion
2001	4.5	67	130	197	$1.2 billion

Source: Derived from M.R. Williams, 2002a. www.msstate.edu/Entomology/Cotton.html

$113/hectare to $158/hectare. Taking into account both crop loss and the cost of control, which is the total cost to US farmers associated with cotton insect pests, this ranged from $187/hectare to $293/hectare which is substantial; these translate to national annual losses in the US due to insect pests of $1.0 billion to $1.7 billion.

Taking into account that a large proportion of cotton is grown in the more tropical developing countries where insect infestations and crop losses are higher, and more insecticide sprays are applied, the total cost associated with cotton insects is substantial. Acknowledging that there is no uniform database and methodology available for calculating precise values of crop losses and control costs associated with cotton insects globally, various data are used to derive estimates that provide indications of the orders of magnitude involved. The US data base (Williams 1997b, 2002a) is by far the most rigorous and detailed, with a long term average for crop loss of 7.5% plus control costs for an average value of approximately $1.4 billion annually. Oerke's estimates of loss for the global regions range from 7 to 24% with an average of about 15%.

With a gross loss in the range of 15% globally, the value of crop losses due to cotton insect pests, based on a $20 billion production in 2000/01 is $3.0 billion plus $1.7 billion for insecticide for a total cost of approximately $5 billion. This estimate is conservative given that: it does not include insecticide application costs; that the average annual cost in the US alone is $1.4 billion over the period 1994 to 2001; and that

China estimates the annual losses to bollworm alone at $1.2 billion (Jia 1998) and India $300 million (King 1994). It is evident from these latter references and others that the bollworm complex is the major component of crop loss associated with cotton insects in both developing and industrial countries. The bollworm cotton complex probably costs cotton farmers worldwide approximately $3 billion annually; this covers yield loss and control costs, excluding labor for sprays. Published experimental data on the increases in production from Bt cotton, when compared with conventional cotton, provide confirmatory evidence that yield increases of 10% or more are representative for the US (Kerby 1996, Benedict and Altman 2001) and up to 30%, or more, in major cotton-growing countries such as India (Naik 2001), which suffer heavy infestations of the bollworm complex. Thus, excluding the substantial labor costs involved in applying many insecticide applications to 33.5 million hectares of cotton, insect pests cost at least $5 billion annually, with bollworms being the principal pest.

9.7 The Global Cotton Insecticide Market

On a global basis, cost of insecticides for cotton at the farmer level in 2001was $1.719 billion (Wood Mackenzie 2002) (Table 33). Cost of insecticide per hectare in developing countries can be as high as $ 200 per hectare in countries such as Brazil. In terms of percentage of cotton production operational costs, insecticides can be as high as 45% in India and Pakistan. Calculated as a percentage of the total spent on insecticides for all crops nationally, the highest is for cotton insecticides in Central and West African countries at 80%, followed by Pakistan at 79%, India at 48% and Brazil at 25%. The reliance on cotton insecticides in developing countries is high and in many cases represents a hardship for producers when the international price of cotton is low and when cotton is the only principal cash crop.

The data in Table 33 present a global overview of the cost of cotton insecticides at the farmer level with a value of $1.719 billion in 2001; this excludes the cost of insecticide application by producers which is significant given a global range of 2 to 12 sprays, with an average of approximately 5.5 sprays on 33.5 million hectares of cotton. By far the largest market for cotton insecticides is in Asia ($961 million), the majority of which is in the developing countries ($811 million), principally India, China and Pakistan. CIS and Australia have markets valued at $92 million and $57 million respectively. It is noteworthy that insecticide sales in China in 2001 decreased by over 10% compared with 2000, whereas sales in India and Pakistan in 2001 were slightly higher. The decrease in China is correlated with a significant increase of approximately 1 million hectares of Bt cotton in 2001. The cost of cotton insecticides for Asia at $ 961 million is 70% higher than the corresponding value for the Americas ($557 million), where

Table 33. Value of Global Cotton Insecticides at Farmer Level, 2001

Region/Country	$ Millions
ASIA	
Developing Countries	811
CIS	92
Australia	57
Subtotal	**961**
AMERICAS	
USA	340
Brazil	179
Latin America (Rest)	38
Subtotal	**557**
AFRICA	**194**
EUROPE	**7**
GLOBAL TOTAL	**1,719**

Source: Wood Mackenzie, 2002. Personal communication.

the major market is the US at $340 million, which is at a similar level to India. The cotton insecticide market for Africa is significant at $194 million, and unlike Asia, there are no major countries like China, India and Pakistan, which dominate and comprise a large percentage of the market – on the contrary the African market comprises 22 countries valued at an average of less than $10 million each. The smallest regional market (valued at $7 million) is Europe, where cotton is grown in Spain and Greece.

In summary, Asia is the continent that captures the largest share (56%) of the global cotton insecticide market followed by the Americas at 32%, Africa 11%, and Europe with less than 1%. Within Asia, the developing countries are by far the most important, representing over 80% of the market with CIS (principally Uzbekistan) and Australia representing only 5% and 3% respectively of the global market. The Americas represent 32% of the global market with the US being the major country representing 60%, Brazil 10% and the balance of 30% in other countries in Latin America.

9.8 The Use of Bt Genes in Cotton

Bacillus thuringiensis is a spore-forming bacterium species that is commonly found in soil. Bt contains a native crystal protein that when ingested by insect pests, causes paralysis in the digestive tract that is lethal. Bt foliar sprays have been used for 50 years to control insect pests and have a long history of safe use. Bt sprays are one of few insecticides permitted for use in organic farming. The commercial Bt cotton available today contains genes from the isolate *B. thuringiensis*, ssp *kurstaki* that produces Cry1Aa, Cry1Ab, Cry1Ac, Cry2A (Benedict and Altman 2001).

9.8.1 Bollgard® and the Chinese Bt Fusion Gene

The Bt genes that are currently deployed are from two sources. Monsanto developed and deployed the Cry1Ac gene in its Bollgard® varieties, which are the most widely used in all nine countries that grow Bt cotton. The second source is the Bt fused gene that was developed by the public sector Chinese Academy of Agricultural Sciences (CAAS) in Beijing, China. The commercial plantings of the CAAS Bt cottons feature a modified Bt fusion gene, Cry1Ab/Cry1Ac, planted in the four provinces of Anhui, Shangdong, Shanxi, and Hubei. (Jia 1998, James 1998). The cowpea trypsin gene, CpTi with a different mechanism of insect resistance to Bt, has also been incorporated by CAAS as a stacked gene with Bt in some varieties. By 1999, the CAAS single gene Bt cottons, and the stacked Bt/CpTi cottons, designed to provide more durable resistance, were planted in nine provinces compared with four in 1998.

The most prevalent Bt gene on a global basis, Cry1Ac, was incorporated into Coker 312 cotton designated MON 531 by Monsanto (Perlak et al 2001) and later named Bollgard® cotton; high transformation efficiency was achieved in Coker with *Agrobacterium tumefaciens*. The transformed Coker was then backcrossed with lines fom Delta and Pine Land and other companies that had the necessary agronomic qualities for commercial acceptance. The data in Table 34 demonstrate the efficacy of the Cry1Ac in Bollgard® in controlling the major lepidopteran pests of cotton. The highest level of control is achieved for pink bollworm (99%) followed by tobacco budworm (95%) and bollworm at 70 to 90%. Control of other cotton pests, cotton leaf perforator and saltmarsh caterpillar is at 85% or more, whereas fall armyworm is at 20%.

The advantages of the Cry1Ac in Bollgard®, over the Bt cotton spray, summarized by Benedict and Altman, (2001), are as follows:

- Active protein provides moderate to high dose control that allows fair to excellent control of selected important lepidopteran pests
- Active protein expressed in all plant parts
- Active protein expressed throughout the season, hence timing of insecticide applications in relation to an infestation is not an issue

Table 34. Estimated Level of Caterpillar Pest Control Provided by Bollgard® I Bt Cotton in the USA

Pest	% Percent Control[1]
1. Pink Bollworm	99
2. Tobacco Budworm	95
3. Bollworm Prebloom	90
Blooming	70
4. Cotton Leaf Perforator	85 or more
5. Saltmarsh Caterpillar	85 or more
6. Fall Armyworm	20 or less

Source: Modified from Benedict and Altman, 2001. Data reproduced with permission of authors, J.H. Benedict and D.W. Altman from the chapter 'Commercialization of Transgenic Cotton Expressing Insecticidal Crystal Protein' pp. 137-201 in J.J. Jenkins and S. Saha (ed) Genetic Improvement of Cotton: Emerging Technologies. Published by Science Publications, Enfield, N.H., USA.

[1] Measured as percent mortality of newly harvested larvae

- Wash off of insecticide during rain, and degradation in sunlight are not issues as they are with spray formulations
- Less farmer exposure to insecticide
- Labor saving technology, due to elimination or reduction of insecticide sprays
- Decreases production risks and provides peace of mind and insurance to farmers at cost-effective control rates
- Contributes to, and provides the foundation for an IPM strategy.

Coincidental with the deployment of the current Bt genes in commercial cotton, R&D programs were developing improved Bt cottons. The first of these to be approved for commercial production was the dual Bt gene Bollgard® II from Monsanto which was approved in September 2002 for planting in Australia for the 2002/03 season with plans to release it commercially in the US once regulatory approval is granted (expected in 2003). Dow AgroSciences have also announced that they expect to launch a dual gene Bt cotton in the US in 2004 (Dow AgroSciences 2002) and Syngenta plans to release a cotton with a novel VIP insect-resistance gene in the US in 2004 with a further release in Australia (Syngenta 2002).

9.8.2 Bollgard® II Cotton

Bollgard®, the first generation Bt cotton developed by Monsanto, with one Bt gene Cry1Ac, has been successfully grown on over 10 million hectares by millions of farmers in nine countries since its introduction in 1996. Producers have benefited from reduced insecticide usage, higher yields and higher economic returns, whereas society has benefited from a safer environment and more affordable cotton prices. Bollgard® has delivered substantial agronomic, environmental health and economic benefits to both small and large farmers in developing and industrial countries.

The Insect Resistance Management (IRM) Strategy for Bt cotton that Monsanto, in conjunction with USDA and universities, developed prior to the introduction of Bollgard® had anticipated further developments of Bt cotton and planned for the development of a second generation of an improved Bt cotton with two Bt genes, now designated Bollgard® II. The new product, Bollgard® II, Event 15985 was developed using particle acceleration plant transformation procedures to add the Cry2Ab gene to the cotton line DP50B that already had the Cry1Ac (Carpenter et al 2002, Rahn et al 2001). The Bollgard® II second-generation of Bt cotton technology contains two different genes that encode proteins from *Bacillus thuringiensis*: Cry2Ab and Cry1Ac; the latter is the protein in the first generation of Bt cotton products. The dual gene cultivars are expected to provide growers with a broader control over a wider variety of insects than achieved with the first generation Bt cotton products while maintaining the excellent control of tobacco budworm (*Heliothis virescens* (F.)) and pink bollworm (*Pectinophora gossypiella* (Saunders)) (Perlak et al 2001). Improved efficacy against several insect pests has been demonstrated in laboratory assays and under field conditions. Laboratory bioassays (Perlak et al 2001) using isolated plant tissue have shown that the dual Bt gene cultivars have increased activity (Table 35) against cotton bollworm (*Helicoverpa zea* (Boddie), control is increased from 84.4 to 92.2%), fall armyworms (*Spodoptera frugiperda* (J.E. Smith), 16.1 to 100%), beet armyworms (*Spodoptera exigua* (Hubner) 50.1 to 94.9%) and soybean looper (1.2 to 97.4% Perlak et al 2001, Stewart et al 2001). Bollworm survival specifically on flower structures was also shown to be significantly lower with the dual Bt gene plants in fresh tissue bioassays (Gore et al 2001). In field studies, cotton genotypes expressing both genes sustained significantly less terminal, square and boll damage from cotton bollworms compared to single gene Bt cotton, albeit under low levels of bollworm pressure (Jackson et al 2001, 2000). Improved field efficacy was also observed for pink bollworm in studies in Arizona, USA (Marchosky et al 2001).

In addition to enhancing efficacy, the dual Bt gene product can, most importantly, serve as a new tool to combat the potential development of insect resistance in cotton fields by providing a second mode of action to control these pests. The Cry2A proteins

Table 35. Relative Efficacy (% Pest Mortality) of Bollgard® and Bollgard® II

Insect Pest	Bollgard®	Bollgard® II
Cotton bollworm	84.4	92.2
Fall armyworm	16.1	100.0
Beet armyworm	50.1	94.9
Soybean looper	1.2	97.4

Source: Perlak et al., 2001.

have characteristics distinct from the Cry1Ac protein (English and Slatin 1992, English et al 1994) and the amino acid sequences of the proteins are quite dissimilar with less than 30% sequence identity (Crickmore et al 1998). Paired genes are one tool used to delay the onset of resistance (Roush 1994, Gould 1998). The evidence indicates that Cry2Ab does provide a second, independent high dose against tobacco budworm and thus the paired toxins may result in redundant control, aiding resistance management strategies (Greenplate et al, In press).

Thus, Bollgard® II represents an important development from three perspectives. First, the two genes reduce the probability of resistance developing and this is a very important contribution to the durability of Bt resistance (Gould 1998); second, it increases the efficacy of control for some of the major lepidopteran pests ,and third it increases the spectrum of pests that can be controlled to include several secondary pests, including armyworms and loopers. Extensive field trials confirm that Bollgard® II provides improved control (Catchot 2001, Norman and Sparks 2001, Lorenz et al 2001, Penn et al 2001, Ridge et al 2000). Gianessi et al (2002) estimated that planting Bollgard® in the US alone in 2001 reduced insecticide applications by 848 MT. Enhanced control with Bollgard® II of the principal cotton bollworm/budworm complex and control of secondary lepidopteran pests should further reduce insecticide requirements in the US and increase yield and collectively facilitate the implementation of IPM and contribute to a more sustainable and profitable cotton production system.

Bollgard® II was approved for use in Australia in September 2002, and it is expected that up to 5,000 hectares will be planted in 2002/03, with a plan for it to replace the single gene construct, INGARD®, entirely in 2004/05. Unlike the single construct, which was limited to 30% of the area, Bollgard® II is not subject to the 30% restriction, and eventually will probably occupy 70% or more of the cotton area in Australia. Approval of Bollgard® II is pending in the US and is expected to be cleared imminently for introduction in the US in 2003. It is likely that Bollgard® I will be phased out of commercial production in the US after Bollgard® II becomes available. Bollgard® II is an important new element in the insect resistant management strategy of cotton insect pests; it provides an additional important tool for facilitating the implementation of IPM, and for optimizing the durability of Bt genes and the multiple and significant benefits they offer.

9.8.3 Other Expected New Insect Resistant Cottons

In 2002, Dow AgroSciences announced the development of a new Bt cotton with traits that confer broad spectrum resistance to lepidopteran pests of cotton; these include tobacco budworm, bollworm, pink bollworm, beet and fall armyworms and loopers. The new Bt cotton product contains the dual genes Cry1Ac and Cry1F, transformed with *Agrobacterium tumefasciens,* and incorporated through back-crossing into several high quality commercial varieties of cotton. (Dow AgroSciences 2002, Personal Communication).

An experimental use permit was filed with the EPA in late 2001 and a complete regulatory package will be submitted following the 2002 season, with full U.S. approval anticipated in early 2004. The new Bt cotton will be marketed through Phytogen Seed Co., and Dow AgroSciences is discussing broad licensing of the product with several other cotton seed companies in the US; opportunities for international marketing of the product are being explored. Import approval for the product is being pursued in Japan, Canada and Mexico.

Syngenta plans to release a cotton with a novel VIP insect resistance gene in the US in 2004 with a further release in Australia (Syngenta 2002).

9.9 Assessment of Risk

Whenever a new technology is introduced there are always issues to be addressed and risks to be assessed. With Bollgard® Bt cotton, the major issues related to two areas – potential risk to the environment, and the potential for insect resistance to develop. There is also a food/feed safety risk assessment conducted because cotton seed oil is used in food and cotton seed meal is fed to livestock.

9.9.1 Assessment of Environmental Risk

9.9.1.1 Agronomic Performance

Prior to the introduction of Bollgard® Bt cotton in the US in 1996, detailed agronomic observations were made in extensive field trials over several years. Agronomic, pest and disease susceptibility observations confirmed that, with the exception of resistance to lepidopteran pests, Bt cotton was agronomically within the normal range of variability for commercial cotton varieties (Hamilton et al 2002). Furthermore, Bollgard® cotton has been grown commercially in the U.S., Australia, Mexico, South Africa, China, Argentina, Colombia, Indonesia and India since initial introduction in the US. No unusual plant pest characteristics or unintended environmental effects have been observed that are attributed to the inserted DNA and expressed proteins, as confirmed by the extensive studies developed prior to, and subsequent to, regulatory approvals and market introduction. Agronomic performance of Bollgard® cotton and protection from damage by Lepidopteran insect pests have been as expected (Edge et al 2001, Benedict and Altman 2001, Gianessi and Carpenter 1999).

9.9.1.2 The donor organisms

The safety of the donor organisms of the C*ry1Ac* and *nptII* genes contained in Bollgard® cotton is well established. The C*ry1Ac* gene encodes the insecticidal protein derived from the common soil bacterium *Bacillus thuringiensis* subsp *kurstaki* (B.t.k.). There is a history of safe use of the Cry1Ac protein in microbial Bt-based products (USEPA 1988, IPCS 2000). Microbial formulations of *Bacillus thuringiensis* (Bt) that contain the insecticidal protein have been registered in numerous countries worldwide, and have been safely used for control of lepidopteran insect pests for more than 40 years (Betz et al 2000). The Cry1Ac protein produced in Bollgard® cotton event 531 is 99.4% identical in predicted amino acid sequence and comparable in biological activity to the Cry1Ac protein found in nature and in commercial Bt microbial formulations (Hamilton et al 2002). *Bacillus thuringiensis* and Bt microbial formulations have been shown to be very specific to the target insect pests, and do not have any deleterious effects on non-target organisms such as beneficial insects (other than closely-related lepidopterans), birds, fish, and mammals, including humans (USEPA 1988, Betz et al 2000). The NPTII protein expressed in Bollgard® cotton is chemically and functionally similar to the naturally occurring NPTII protein. The NPTII protein (donor is *E. coli*) is ubiquitous in the environment and found in microbes present on food and within the human digestive system (Fuchs et al 1993, USFDA 1994).

9.9.1.3 Effect on non-target organisms

There is extensive information about microbial preparations of *Bacillus thuringiensis* subsp. *kurstaki (B.t.k)* containing Cry proteins, including the Cry1Ac protein, which demonstrate that these proteins are non-toxic to non-target organisms (USEPA 1988, Betz et al 2000). The literature has established that the Cry1Ac protein is selective for lepidopteran insects, binds specifically to receptors on the mid-gut of lepidopteran insects and has no deleterious effect on beneficial/non-target insects. The safety of the Cry1Ac protein expressed in Bollgard® cotton to non-target organisms was confirmed on several representative organisms (Hamilton et al 2002). With the use of in-plant Bt technology, non-target, beneficial insects are not harmed as they are with many broad spectrum insecticidal sprays (Benedict and Altman 2001). Bt protein affects a specific set of target pests, and unrelated non-target pests are not affected. However, pyrethroids have been demonstrated to affect a broad range of non-target species (Badawy and El-Arnaouty 1999). Therefore, since the use of Bollgard® cotton has resulted in a reduction in conventional synthetic insecticide applications (Gianessi and Carpenter, 1999) increased populations of beneficial insects in Bollgard® cotton fields are expected. Several studies have shown that predatory non-target organisms can be more active in Bollgard® cotton as biological control agents for secondary pests (Edge et al 2001). Post commercial monitoring indicates that populations of predatory, non-target organisms are significantly higher in Bt cotton than in non-Bt cotton that was sprayed with insecticides, (Head et al In Press a, Head et al 2001, Roof and Durant 1977) and provide biological control of secondary pests. Studies have reported lower levels of secondary pests such as Spodoptera in Bt cotton related to the higher number of predator insects present (Smith 1977).

9.9.1.4 Potential of Bt cotton to develop as a weed

Gossypium hirsutum is well characterized and has a safe history of production under a broad range of agricultural environments. Past intensive selection to develop germplasm adapted to high productivity under agricultural conditions makes it unlikely that cotton could effectively compete and survive in the environment as a weed. Cotton is not found as a weed in the global cotton production areas. Bollgard® cotton does not have any different weediness characteristics than other conventional cotton varieties (Hamilton et al 2002). Bollgard® cotton does not exhibit different agronomic or morphological traits compared to controls, that would confer a competitive advantage over other species in the ecosystem in which it is grown. Also, there is little probability that any Gossypium species crossing with Bollgard® cotton could become more weedy. Thus, there is no evidence that insertion of the Cry1Ac coding sequence into the cotton genome has had any effect on the weediness potential of the cotton plant.

9.9.1.5 Environmental consequences of pollen transfer

Cotton is predominantly a self-pollinating crop but can be cross-pollinated by certain insects (Niles and Feaster 1993). However, outcrossing of the *Cry1Ac coding sequence* from Bollgard® cotton to other *Gossypium* species or to others of the malvacea family is extremely unlikely for the following reasons (Percival et al 1999):

- Cultivated cotton is an allotetraploid and is incompatible with cultivated or wild diploid cotton species;

therefore, it cannot cross and produce fertile offspring.

- Although outcrossing to wild or feral allotetraploid *Gossypium* species can occur, commercial cotton production generally does not occur in the same geographical locations as the wild relatives. For example, outcrossing to *G. tomentosum* in Hawaii is possible, but no commercial cotton is grown in Hawaii.

- There are no identified non-cotton plants that are sexually compatible with cultivated cotton.

Volunteer plants are not a significant issue and can be controlled with many registered herbicides. Thus, the environmental consequences of pollen transfer are negligible due to limited movement, natural genetic barriers that preclude outcrossing with native cotton, with no known compatibility with any wild relatives. The safety of the Cry1Ac protein is well documented and the *cry1Ac* gene would not confer any competitive advantage (Hamilton et al 2002).

9.9.2 Insect Resistance Management (IRM)

Several publications (Roush 1999, Benedict and Altman 2002, Fitt 2002/In Press) have discussed the potential development of resistance to Bt cotton at some length, and the reader is referred to these texts for a detailed discussion. The intent here is to provide an overview of insect resistance management strategies that have been in place for six years since Bt cotton was first commercialized in 1996.

There is no doubt that the potential development of resistance poses a significant challenge in the effective deployment of Bt cotton, but the same challenge also applies when attempting to develop effective insecticides, or other means of control. Experience with conventional breeding to enhance insect resistance in crops, and particularly experience with developing insecticides to control insect pests of cotton supports the case that an insect resistance management strategy is essential in order to preserve the durability of product effectiveness, irrespective of the source or mode of control. In the specific case of cotton pests and Bt, there is ample evidence that cotton bollworm, *Helicoverpa armigera* as well as other lepidopteran pests have developed resistance to a multitude of insecticides. Resistance to topical Bt spray applications has also developed in field populations of diamond back moth (Tabashink 1994). Thus, it is critically important that Bt and other genes that confer resistance to the major lepidopteran pests be managed and deployed responsibly and effectively with an IRM strategy, recognizing that different IRM strategies must be developed to meet different needs. For example, the needs of a typical small farmer growing less than a hectare of cotton in a developing country are quite different to the needs of large commercial farmers growing a large block of 100 hectares or more of Bt cotton in an industrial country. Appropriate IRM strategies have been developed in countries where Bt cotton has been commercialized, usually involving public and private sector entities working together towards the mutual objective of preserving the durability of resistance.

Whereas specific IRM strategies need to be developed to meet the needs of particular cotton production systems, the factors that impact on the development of resistance to Bt, conventional insecticides, or conventional host plant resistance are the same (Head et al in Press b; Shelton et al 2000, Roush 1997). These three factors are:

- The specifications of the source of resistance and its deployment (e.g. high dose and refugia).
- The genetics of insect resistance (frequency and dominance of the resistance alleles).
- Insect behavior, movement and mating.

Based on knowledge of the above three factors, specific IRM strategies have been developed for specific cotton production systems that feature:

- An appropriate spatial and temporal expression of the Bt gene.
- Appropriate refugia where susceptible insect pests can breed and multiply.
- Use of Bt in conjunction with other means of control in an IPM strategy.
- The development and deployment of other genes that confer control based on different mechanisms or modes of action.
- Monitoring system for detecting resistance and a plan for implementing remedial action.

When the first Bt cotton application was submitted for consideration in the US in 1995, the inclusion of an IRM plan as part of the registration of Bollgard®, during discussions with EPA and Monsanto, was unprecedented (Roush 1997). The IRM plan was developed as a result of collaboration between USDA, universities, and Monsanto to articulate a deployment strategy over the short, medium and long term, (Table 36). The US IRM strategy features a short term program utilizing a high dose of Bt, refugia, agronomic practices that limit exposure of pests to the active protein, implemented in association with an IPM strategy and a rigorous monitoring system for the early detection of resistance. The short term strategy is fortified by a mid term strategy to develop a Bt cotton with two genes, a remediation strategy and a 'community refuge option' to promote grower flexibility and maximum IRM compliance. The long term strategy includes all the elements in the short and mid term plus the incorporation of host plant resistance and other novel insecticide genes, as well as defining the value of alternate hosts as contributors to the overall refuge. It is noteworthy that since its inception in 1996, the US strategy has operated effectively and that key projected products, such as Bollgard® II have already been successfully developed, approved in Australia and ready for release in the USA. Similarly, the stringent IRM in Australia, successfully implemented since 1996, has already been revised to incorporate Bollgard® II in 2002. China has successfully implemented a different IRM strategy featuring a Bt fused gene in conjunction with CpTi and a rigorous monitoring system. Other countries growing Bt cotton including India, Indonesia, Mexico, Argentina, and South Africa, have also developed and implemented IRM strategies to meet their specific needs and have precluded the development of resistance to-date.

The use of transgenic Bt cotton, deserves continued careful attention (Gould 1998) because cotton insect pests are subject to continuous selection throughout the season. Development of resistance could jeopardize the use of Bt as a conventional spray by farmers including organic growers, which is of particular concern to many NGOs opposing biotechnology. From the time that Bt cotton was introduced in 1996, some critics have predicted that the development of resistance was imminent. Indeed, claims have been made by critics that resistance has already developed, but to-date investigation has consistently failed to confirm those claims. Whereas the risk of resistance developing is real, requiring the implementation of rigorous IRM strategies, it is equally important to acknowledge the significant benefits that have already been delivered following the planting of 13 million hectares of Bt cotton globally since 1996. Had Bt cotton not been deployed in 1996, these significant benefits would not have been realized at an enormous opportunity cost to millions of farmers who grew 13 million hectares of Bt cotton in eight countries. It is noteworthy that despite predictions to the contrary by critics, insect resistance to Bt cotton has not yet been detected in the large area of Bt cotton deployed globally. Since the introduction of Bt cotton in 1996, the Bt genes Cry1Ac, the fused gene Cry1Ab/Cry1Ac, and the cowpea trypsin CpTi gene have been successfully deployed to confer resistance against lepidopteran cotton pests. Notably, in the interim, Bollgard® II has been developed which provides a second line of defense and more effective control. Bollgard® II is already approved in Australia for the 2002/03 season and approval is expected for the US in 2003. Other products that are also expected to be available in the near term include a dual Bt gene cotton (Cry1Ac and Cry1F) from Dow AgroSciences in 2004 and an insect resistant cotton with a VIP gene from Syngenta in the same year. The private and public sectors in both developing (China and India) and industrial countries (USA and Australia) have active programs to develop new Bt and other novel genes as well as the incorporation of improved conventional host plant resistance.

Table 36. Insect Resistance Management Strategy for Bollgard® Cotton

SHORT TERM

High-dose of active protein to control insects with heterozygous alleles for resistance.
Refugia of non-Bt cotton to produce susceptible insects.
Agronomic practices that minimize insect exposure to active protein.
Integrated pest management to increase beneficials, and reduce conventional insecticide use.
Monitoring target insect populations for susceptibility to active protein.
Report on Bt cotton performance, especially any "failures". Investigate cause.

MEDIUM TERM

Continue with short term strategy.
Development of a remediation strategy.
'Community Refuge Options' to promote grower flexibility and maximum IRM compliance.
Combine 2 insecticidal genes with different target sites/modes of action.

LONG TERM

Continue with short and medium term strategies plus:
Additional refuge options to promote grower flexibility and maximum IRM compliance.
Refine value of alternate hosts as contributors to overall refuge,
Incorporate host plant resistance traits into Bt cotton.
Incorporate other novel insecticidal genes.

Sources: Mullins, 2002 Personal communication. Modified version of Benedict and Altman (2001) and reproduced with permission of authors, J.H. Benedict and D.W. Altman from the chapter 'Commercialization of Transgenic Cotton Expressing Insecticidal Crystal Protein' pp.137-201 in J.J. Jenkins and S.Saha (ed) Genetic Improvement of Cotton: Emerging Technologies. Published by Science Publications, Enfield, N.H., USA.

IRM jointly developed by Monsanto, USDA and Universities.

Thus, in summary the development and implementation of IRM strategies in conjunction with the introduction of Bt cotton in 1996, and its expansion to cover approximately 4.3 million hectares in 2001, have made a significant contribution to the effective deployment of Bt genes. Society has placed a high value on Bt cotton because it can reduce by at least half the volume of broad spectrum conventional insecticides applied to cotton with significant economic, environmental and social benefits and health implications for producers, particularly small farmers in developing countries. It is reassuring to know that the initial plan to broaden and diversify the mechanisms of resistance is materializing in terms of new approved products such as Bollgard® II and that other new Bt genes and novel resistance genes are expected in the near term. However, these expectations should not lead to complacency and any relaxing of the rigor with which Insect Resistant Management strategies are implemented by small and large farmers in both developing and industrial countries. It would be valuable now to convene an international Review of Insect Resistant Management Strategies that would consolidate the considerable knowledge and experience gained thus far, and utilize it to develop an international strategy that could guide implementation coincidentally with the further expansion of Bt cotton globally in the near term. This would be particularly important for the large number of developing countries that stand to benefit significantly from Bt cotton but require assistance to ensure that Bt cotton is deployed effectively.

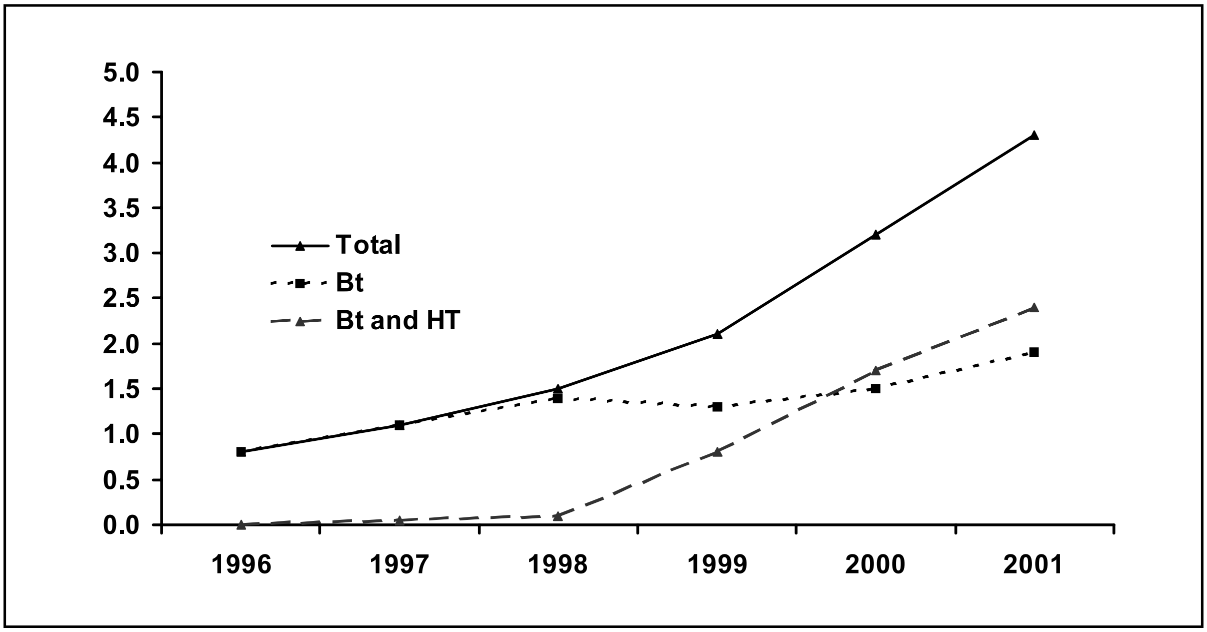
9.10 Global Adoption of Bt Cotton

Bt cotton was first introduced in the US on 730,000 hectares in 1996 (James and Krattiger 1996) with additional small hectarage in Mexico and Australia for a global total of approximately 0.8 million hectares (Table 37). China adopted Bt cotton in 1997 and the stacked genes of Bt and herbicide tolerance were introduced in the US in 1997 (James 1997); by 2001 the stacked gene product accounted for 55 % of all the global commercial cotton containing the Bt gene, compared with 45% of the single Bt gene. By 1998 the hectarage of Bt cotton had doubled to 1.5 million hectares and it was grown in a total of six countries, USA, Mexico, Australia, Argentina, China and South Africa. Between 1996 and 2001, when Indonesia grew Bt cotton for the first time a total of 13 million hectares (Table 37) was grown by seven countries (James 2001, 2000a, 2000b).

Figure 7 shows the global adoption of Bt cotton since its introduction in 1996. In six years Bt cotton has increased more than five fold from 0.8 million hectare in 1996, to 2.1 million hectares in 1999, to 4.3 million hectares in 2001. Assuming a global average of 34 million hectares of cotton the % global adoption with Bt cotton has increased from 2% in 1996 to 13% in 2001.

Notably in 2002, India, the largest cotton-growing country in the world, which accounts for 25 % (8.7 million hectares) of global hectarage, grew 44,500 hectares of

Figure 7. Global Adoption of Bt Cotton (Bt and Bt/Herbicide Tolerance) 1996 to 2001 (Millions of Hectares)



Source: Clive James, 2002.

Table 37. Global Adoption of Bt Cotton (Bt and Bt/Herbicide Tolerance) 1996 to 2001 (Millions of Hectares)

Trait	1996	1997	1998	1999	2000	2001	Total
Bt	0.8	1.1	1.4	1.3	1.5	1.9	**8.0**
Bt and HT	0.0	<0.1	0.1	0.8	1.7	2.4	**5.0**
Total	**0.8**	**1.1**	**1.5**	**2.1**	**3.2**	**4.3**	**13.0**

Source: Clive James, 2002. HT is herbicide tolerance.

Bt cotton for the first time. In 2002, Colombia in South America also approved 2,000 hectares of pre-commercial plantings of Bt cotton. Thus, in 2002 there are nine countries commercializing Bt cotton, seven developing countries, three from Asia (China, India and Indonesia), three from Latin America (Mexico Argentina and Colombia) and on the African continent, South Africa. The two industrial countries that are commercializing Bt cotton are the USA and Australia. It is noteworthy that up to 5 million farmers grew Bt cotton in 2001, of which 99% were in developing countries. Approximately 25,000 large farmers benefited from the technology in the industrial countries of the USA and Australia. The vast majority of the 4 to 5 million Bt cotton farmers in the developing countries in the South are resource-poor farmers, mainly in China and also in South Africa, who have derived substantial economic, environmental, health and social benefits (Pray et al 2002, Ismael et al 2002 a,b,c) that have contributed to the alleviation of poverty and a better quality of life.

9.11 Country Case Studies

9.11.1 USA Case Study: Bt Cotton

Country Profile

Population	273 million
Arable as % of total land	19%
Agriculture as % of GDP	1.3%
Agriculture as % employment	3%
Cotton area (ha)	5.7 million
Lint production (MT)	4.5 million
No. of cotton farmers	30,000

Introduction

In 2001/02 the US grew 5.7 million hectares of cotton with a lint yield of 790 kg/hectare for a total production of 4.5 million MT. The US is by far the largest exporter of cotton (2.4 million MT) representing almost 15% of global exports of 19.9 million MT. The US has the second largest area of cotton in the world (5.6 million hectares) after India (8.7 million hectares) and is the second largest producer (4.5 million MT) after China (5.3 million MT).

Cotton is the fifth largest crop in the US by area and in recent years the value of the crop has been about $4 billion. Cotton is grown in the south and in the west in 16 states. Texas is the largest producer of cotton (30%), followed by Georgia. Cotton production systems range from low input rainfed cotton in Texas to the very intensive systems of Arizona, California and New Mexico. There is an extensive literature on Bt cotton in the US that includes several comprehensive reviews (Gianessi et al 2002, Carpenter et al 2002, Benedict and Altman 2001, Edge et al 2001, Carpenter and Gianessi 2001). The aim in this case study, is to provide a brief overview of Bt cotton in the USA.

Cotton Insect Pests and Crop Losses

Of the lepidopteran pests, the cotton bollworm (*Helicoverpa zea*), pink bollworm (*Pectinophora gossypiella*) and tobacco budworm (*Heliothis viriscens*) are the major pests of economic importance. These three pests are often called the bollworm/budworm complex. Boll weevil, *Anthonomus grandis*, is also important but a rigorous scheme is underway to eradicate this pest. Other secondary lepidopteran pests include beet and fall armyworms, loopers and cutworms.

The potential losses due to insects, in the absence of any form of control in the US is estimated at 38% and the actual losses that occur despite the application of control is estimated at 11% (Oerke 2002). More detailed surveys of losses due to cotton insects in the US indicate that crop losses range from 4.5% in 2001 to 11% in 1995 (www. msstate.edu/ entomology/cotton). The average loss reported for the 18 year period 1979 to 1996 was 7.5% (Williams 1997b) with the bollworm/budworm complex reported to be the most important pest in 13 out of the 18 years.

For the period 1994 to 2001 cotton insect losses in the US have ranged from 4.5% in

Table 38. Losses Due to Cotton Insect Pests in the US and Cost of Control by Insecticides and Other Means, 1994 to 2001

	Yield Loss %	Yield Loss $/Ha	Control Costs $/Ha	Loss + Control $/Ha	Value of Loss and Control (National US)
1994	6.0	65	123	187	$1.0 billion
1995	11.1	140	145	285	$1.7 billion
1996	6.6	110	113	225	$1.2 billion
1997	9.4	145	133	278	$1.5 billion
1998	8.0	128	158	286	$1.2 billion
1999	7.7	108	125	233	$1.3 billion
2000	9.3	138	155	293	$1.7 billion
2001	4.5	67	130	197	$1.2 billion

Source: M.R. Williams, 2002a. www.msstate.edu/Entomology/Cotton.html

2001 to 11.1% (Table 38) with the value of loss per hectare ranging from $65/hectare to $145/hectare with an average of approximately $100 per hectare. This translates to an annual loss of approximately $500 million at the national level in the US. In addition to the $ value of crop loss, the US data in Table ll also includes the cost of control, the major portion of which is insecticides and their application. During the period 1994 to 2001, control cost ranged from $113/hectare to $158/hectare. Taking into account both crop loss and the cost of control, which is the total cost to US farmers associated with cotton insect pests, this ranged from $187/hectare to $293/hectare which is substantial; these translate to annual losses in the US due to insect pests of $1.0 billion to $1.7 billion.

Adoption of Bt Cotton

Bt cotton (Cry1Ac), developed by Monsanto and Delta Pine Land, was introduced in 1996, principally to control the three major pests: tobacco budworm, cotton bollworm and pink bollworm. In the US, in the mid south and south east, cotton bollworm and tobacco budworm are the most prevalent pests, whereas pink bollworm is the most prevalent in the western states. Before the introduction of Bt cotton in 1996, 75% of the cotton area was treated with insecticides and an average of 2.4 sprays were specifically applied to control the bollworm/budworm complex which was estimated to cause a loss of 4%, despite the application of insecticides (Carpenter and Gianessi 2001). In 1995, the year prior to the introduction of Bt cotton, tobacco budworm infestations were particularly high causing estimated losses of

29% in Alabama (Williams 1996). This was due to the development of resistance to the insecticides used.

The increase in adoption, depicted in Table 39, indicates a high rate of adoption starting from 14% in 1996 to 34% in 2001 (Edge et al 2001); these estimates are based on USDA/NASS data, whereas USDA.AMS data indicate that the percentage Bt in 2001 was 39%. Over 2 million hectares of Bt cotton were grown in the US in 2001; they include varieties with the single Cry1Ac Bt gene (10% of all Bt cotton) and varieties with the stacked genes of Bt and herbicide tolerance (90%).

Yield Advantage of Bt Cotton

Extensive field trials in the US report a range of results indicating that on average, Bt cotton will yield 10% or more than conventional varieties (Perlak et al 2001). In a 55 field comparison Kerby (1996) reports an average increase of 18% with a range of 15 to 21% (Table 40). Benedict and Altman (2001) report an average yield increase of approximately 14%, equivalent to 175 kg/hectare of lint.

It is evident that the yield advantage of Bt cotton will be dependent on many factors particularly the infestation level of pests, which will vary from year to year and state to state. Taking these variables into account the National Center for Food and Agricultural Policy (Carpenter and Gianessi 2001, Gianessi et al 2002) have estimated the increase in production of cotton in the US in 1998, 1999 and 2001 (no estimate was generated for 2000). The data in Table 41 indicate that the yield advantage of Bt cotton in 1998 was 80,704 metric tons (MT), 117,935 MT in 1999, (2000 data not available) and 84,085 MT in 2001. Thus, in 2001 Bt cotton produced an average of 40 kg/hectare more yield, on 2.08 million hectares for a total gain of 84,085 MT valued at $115 million or approximately $50/hectare.

Reduction of Insecticides

Bt cotton has led to a consistent decrease in the number of insecticide sprays required. Benedict and Altman (2001) estimate that the overall average reduction is 2.2. This is consistent with other estimates which calculate a reduction of approximately 2. In terms of active ingredients, Benedict and Altman calculated that in 1998 this translated to a saving of 1.09 million kg (a.i.) of insecticide equivalent to 1,090 MT on 1.1 million hectares of Bt cotton. The estimate of Carpenter and Gianessi (2001) for 1998 is of the same order as Benedict and Altman (2001) at 907 MT. Savings of insecticides for the three years 1998, 1999 and 2001 are detailed in Table 41 (2000 data not available). The data indicate that on average about 1,000 MT of insecticide (a.i.) was saved annually. For 2001, when infestation of lepidopteran pests was the lowest in recent years, 848 metric tons of insecticide (a.i.), equivalent to 0.45 kg/hectare was saved (Gianessi et al 2002, Carpenter and Gianessi 2001).

There are secondary benefits associated with the deployment of Bt cotton, requiring less

Table 39. Adoption of Bt Cotton in the USA

Year	US Cotton Area Million Hectares	Bt Cotton Area Million Hectares	Bt Cotton Area (% of Total)
1996	5.20	0.73	14
1997	5.40	1.05	20
1998	4.30	1.17	27
1999	5.90	1.58	27
2000	6.20	2.10	34
2001	6.20	2.08	34

Sources: www.usda.gov/nass; Edge et al., 2001. Reproduced with the permission of the authors, from the Journal of Cotton Science and the Cotton Foundation, Memphis, TN, USA.

Table 40. Lint Yields for Bt Cotton Varieties and Their Non-Bt Near Isogenic Parents

Variety	Lint Yield (Kg/Ha)	Yield Difference Kg/Ha (Bt minus non-Bt)	% Yield Change (Bt versus Non-Bt)
NuCOTN33B Bt	1,215	+ 207	+20.5%
DP5415 non-Bt	1,008		
NuCOTN35B Bt	1,117	+143	+14.7%
DP5690 non-Bt	974		
Average NuCOTN Bt	1,167	+176	+17.7%
Average non-Bt	991		

Source: Benedict and Altman, 2001. Data reproduced with permission of authors, J.H. Benedict and D.W. Altman from the chapter 'Commercialization of Transgenic Cotton Expressing Insecticidal Crystal Protein' pp.137-201 in J.J. Jenkins and S.Saha (ed) Genetic Improvement of Cotton: Emerging Technologies. Published by Science Publications, Enfield, N.H., USA.

[1] Data from 55 field trials in 1994-1995

Table 41. US National Benefits from Bt Cotton

	Production Increases MT	Insecticide Reduction MT	National Benefit $M	Benefit $/Ha	Bt Cotton Ha Million
1998	80,704	907	92	84	1.10
1999	117,935	1,224	99	52	1.89
2001	84,085	848	103	50	2.08

Source: Carpenter and Gianessi, 2001; Gianessi et al., 2002.

insecticide, which include the following: more favorable environment for non-target predatory insects that act as biological control agents for secondary pests; less insecticide pollution of soil; less contamination of water sources and aquifers with insecticide run off; more favorable environment for wild life, e.g. birds that depend on insects for food; less packaging for insecticides reducing waste; lower application costs; more flexible insect control programs, etc.

Overall Economic Advantage of Bt Cotton

The yield increases and decreased costs of insect control associated with Bt cotton are partially offset by higher costs of seed for Bt cotton. Taking these factors into account, overall economic benefits for farmers in 1998 were estimated at $84/hectare equivalent to a national benefit of $92 million. Similarly, for 1999 the economic advantage of Bt cotton was $52/hectare for a national benefit of $99 million (Table 41) and for 2001 it was $50/hectare for a national benefit of $103 million (Carpenter and Gianessi 2001;Gianessi et al 2002). These estimates are of the same order as EPA estimates that range from $60 to $ 126 million annually. Thus, in summary the overall economic benefit for Bt cotton growers in USA is $50/hectare to $85/hectare, (after deducting additional costs related to seed and insect protection), which translated to approximately $100 million/year for the 2 million hectares of Bt cotton in the US in 2001 at current world prices of cotton.

Distribution of Benefits

One of the "corporate concerns" often voiced by the critics of biotechnology relates to their perception that the developers of GM crops, usually transnationals, are the major or sole beneficiaries from GM crops. On the contrary, analyses of Bt cotton in the US over the 3 year period 1996 to 1998, consistently show that farmers have been the major beneficiaries. Data in Table 42 indicate that farmers gained 59%, 42% and 46% of the total surplus in 1996, 1997 and 1998 respectively, compared with 21%, 35% and 34% for the technology developers and only 5%, 9% and 9% for the

Table 42. Distribution of Economic Surplus Expressed as % from Bt Cotton in the USA

Beneficiary	1996[1]	1997[2]	1998[3]
Farmers	59	42	46
Technology Developers	21	35	34
Seed supplier	5	9	9
Consumers	9	7	7
Net Rest of the World	6	7	4
Total	**100**	**100**	**100**

Source: James, 2001 from following resources: [1]Falk-Zepeda et al., 2000b; [2]Falk-Zepeda et al., 2000a; [3]Falk-Zepeda et al., 1999.

seed supplier. Thus on average farmers capture approximately 50% of the surplus compared with 30% for the technology developers. The share of benefit to consumers can be expected to increase, as the higher Bt cotton yields will increase supply and decrease prices, thereby providing consumers with more affordable cotton.

Highlights

- **USA is the second largest producer of cotton in the world (4.5 million MT) and by far the largest exporter (2.4 million MT).**

- **Bt cotton was introduced in the US in 1996 and currently occupies between 35 and 40% of the total cotton area of approximately 6.0 million hectares.**

- **Benefits from Bt cotton include an average increase of 10% or more in yield, a reduction of 2.2 insecticide sprays that translated to approximately 850 MT less insecticide used in 2001, with significant positive implications for the environment.**

- **These benefits, offset by the higher cost of Bt seed, result in an overall economic benefit of a minimum of $50 to $85 per hectare which translated to a national benefit of approximately $ 100 million in 2001.**

- **Farmers are the major beneficiaries of the economic benefits from Bt cotton, capturing approximately 50% of total benefits compared with 30% for the technology developers.**

9.11.2 Australia Case Study: Bt Cotton

Country Profile

Population	19 million
Arable as % of total land	7%
Agriculture (including mining) as % of GDP	8%
Agriculture as % employment	5%
Cotton area (ha)	400,000
Lint production (MT)	670,000 MT (2001/02)
No. of cotton farmers	1,220

Introduction

In 2001/02 Australia grew 404,000 hectares of cotton, with the highest lint yield in the world of 1,658 kg/hectare, for a total production of 670,000 MT; it consumed only 15,000 tons and exported 700,000 tons (ICAC 2002). Cotton production is highly mechanized and intensively managed with irrigation, and inputs including fertilizer and insecticide. The deployment and impact of transgenic Bt cottons in Australia has recently been reviewed comprehensively (Fitt 2002 Personal Communication/In Press) and is the source of information for this case study. All costs are quoted in Australian dollars (A$) where A$1.00 is equivalent to US$0.55.

Insect Pests of Cotton

The two principal insect pests are Australian budworm (*Helicoverpa punctigera*), and the bollworm, *H. armigera*; the former causes damage early in the season whereas the latter bollworm causes more damage later in the season. Bollworm has evolved a high degree of resistance to the various classes of insecticides which are employed in an integrated pest management (IPM) strategy. Other insect pests include thrips, mirids, aphids, and spider mites. Pest management accounts for 35 to 40% of operational costs and can range from A$400 (US$220) to A$1,000 (US$550)/hectare.

Adoption of Bt Cotton

Bt cotton was field tested and commercially released in 1996/97. The *Cry1 Ac* gene from Monsanto has been incorporated in CSIRO varieties (INGARD®) and Bt cotton varieties are sold by Cotton Seed Distributors and Delta Pine Land. The area of Bt cotton increased from 30,000 hectares in 1996/97 to 165,000 hectares in regulated annual step increases of 5% up to a maximum of 30% which was reached in 2000/01, and held at that same level in 2001/02 (Table 43). The registration of Bt cotton was conditional on the establishment of a resistance management strategy overseen by a committee with representatives from farmers, scientists from the public and private sectors. Resistance management is assigned a very high priority and the limit of 30% Bt cotton is designed to provide the other 70% of cotton as an additional refuge to the required regular refuge; the latter requires 10 hectares of unsprayed cotton per 100 hectares of Bt cotton, or 100 hectares of sprayed conventional cotton, which is the preferred

Table 43. Adoption of Bt Cotton in Australia

Year	Area Bt Cotton (Ha)	% of Total Cotton (Ha)
1996-1997	30,000	8
1997-1998	60,000	15
1998-1999	85,000	20
1999-2000	125,000	25
2000-2001	165,000	30
2001-2002	146,000	30

Source: 1996-1997 to 2000-2001 Fitt (2002 Pers. Comm./In Press); 2001-2002. Fitt, 2001 Personal Communication.

option of farmers. Bt cotton was introduced with a license fee of A$245 (US$135)/hectare which was later reduced to A$155 (US$85)/hectare. Experience with Bt cotton in Australia showed that whereas Bt provides good control of *Helicoverpa* early in the season, its effectiveness decreases in late season requiring supplementary sprays; the performance of Bt cotton has also been found to vary by location.

Effect on Yield

The data on yield for Bt cotton and non-Bt cotton in Table 44 summarizes yield performance over a four year period. There is no significant yield gain or loss from using Bt cotton in Australia. The average yield of Bt cotton over the four year period was 7.8, and 8.0 bales/hectare for non-Bt cotton, respectively.

Reduction in Insecticide Use

There has been a significant and consistent decrease in the number of sprays required by Bt cotton compared with non-Bt cotton (Table 45). The average number of sprays required by Bt cotton (6.5) is 40% less than that required by non-Bt cotton (11.2). The reduction of 4.7 sprays due to Bt cotton assumes high priority in Australia since it is a major contribution to a safer environment and it also provides a foundation on which a more sustainable IPM strategy can be built. In the first two years, insect control costs, which included the technology fee were actually higher for Bt cotton (Table 46). However, in 1998/99 and 1999/00 the net benefit was in favor of Bt cotton at A$91 (US$50) and A$72 (US$40)/hectare respectively. The 4.7 spray reduction in Table 45 compares with a reported reduction of 7.7 sprays (Addison 1999).

Economic Advantage of Bt Cotton

In the initial year, Bt cotton had a significant negative economic benefit of minus $262/hectare due to higher insect control costs,

Table 44. Yield (Bales/Hectare) of Bt Cotton Compared with Non-Bt Cotton in Australia

	1996-1997	1997-1998	1998-1999	1999-2000	Average
Bt	7.73	8.42	6.83	8.05	7.78
Non-Bt	8.26	8.38	7.39	7.98	8.00
Bt - Non-Bt	**(-0.53)**	**+0.04**	**(-0.56)**	**+0.07**	**(-0.24)**

Source: Fitt, 2002. Personal Communication/In Press.

Table 45. Reduction in Number of Insecticide Sprays with Bt Cotton in Australia

	1996-1997 # of Sprays	1997-1998 # of Sprays	1998-1999 # of Sprays	1999-2000 # of Sprays	Average
Non-Bt	10.3	10.0	14.0	10.3	11.2
Bt	5.0	6.0	8.7	6.2	6.5
Non-Bt - Bt	**5.3**	**4.2**	**5.3**	**4.1**	**4.7**

Source: Fitt, 2002. Personal Communication/In Press.

Table 46. Insect Control Cost (A$/Hectare) for Bt Cotton and Non-Bt Cotton in Australia

	1996-1997	1997-1998	1998-1999	1999-2000	Average
Non-Bt	467	456	766	573	565
Bt	508	491	675	501	544
Non-Bt - Bt	**(-41)**	**(-35)**	**+91**	**+72**	**+21**

Source: Fitt, 2002. Personal Communication/In Press.

lower yields and exacerbated by a high technology fee of A$245/hectare. When the technology fee was lowered to A$155, this resulted in relatively lower insect control costs for Bt cotton, which translated to a break-even or modest net economic benefits ranging from A$6 (US$3)/hectare in 1998/99 to A$50 (US$28)/hectare in 1999/00. It is noteworthy that the variance associated with net economic benefits is significant; for example, for the average of A$50/hectare in 1999/00 the range was from minus A$1,400/hectare to plus A$2,000/hectare. Despite modest economic returns from Bt cotton, farmers have purchased the full quota of seed available each year because they are convinced of its environmental benefits and that it provides a foundation for a sustainable IPM strategy.

The advantages of higher densities of beneficial insects, and the reduced negative effects of broad spectrum insecticides are assigned high 'economic value', although they are intangible. In addition, greater farm management flexibility and efficiencies from reduced sprays provide real value to growers not considered in this analysis. The principal 'economic gain' of Bt cotton is the fact that farmers are not required to operate an intensive spray control program throughout the season, with its associated negative effects on the implementation of the IPM program.

Concluding Comments

Prior to the introduction of Bt cotton, Australia concluded that the principal challenge with Bt cotton was the risk associated with the potential development of resistance to the Cry1Ac protein. This has shaped policy in terms of limiting Bt cotton to 30% of the cotton area, rigorous refuge, scouting and monitoring systems to detect resistant insects and a commitment to IPM, in which Bt cotton plays a strategic role.

The new double construct Bollgard® II Bt cotton, with the two genes *Cry-1-Ac* and *Cry-2-Ab* was approved by the Office of the Gene Technology Regulator for Australia in September 2002. This was the first approval for the product globally, with clearance in the US expected imminently thereafter. It is planned that up to 5,000 hectares of Bollgard® II will be planted in Australia in the 2002/03 season, increasing to 50,000 hectares in 2003/04. Both INGARD® and Bollgard® II will be sold in 2003/04. INGARD® will be withdrawn in 2004/05 and replaced by Bollgard® II. Unlike INGARD®, which was restricted to 30% of the cotton area, the planting area of Bollgard II is not capped and could reach up to 70 or 80% of the crop. Bollgard II is more effective than Bollgard I, and will further reduce insecticide requirements and most importantly provide more durable resistance (Reuters, 2002).

Highlights

- **Australia has an intensive cotton production system that has the highest yields in the world; it exports over 90% of its production.**

- High dependence on insecticides, with its negative impact led Australia to assign high priority to the implementation of an Integrated Pest Management strategy that would allow sustainable production of cotton.

- Bt cotton was introduced into Australia (INGARD®) in 1996/97 with regulatory requirements for large refuges, a phased introduction with a limitation that Bt cotton should not exceed 30% of the cotton area. The potential development of resistance to Bt is seen as the greatest challenge and this guides and influences policy and deployment of Bt cotton.

- The principal benefit of Bt cotton is its contribution to decreasing by almost half (11.2 to 6.5), the number of insecticide sprays/season, with positive implications for the environment and sustainability. Economic benefits have been modest with no significant increases in yield, but reduced costs for insect control.

- The introduction of the double construct Bollgard® II Bt cotton with the two genes *Cry 1Ac* and *Cry 2Ab* was approved in September 2002 and up to 5,000 hectares of Bollgard® II are expected to be grown in 2002/03. Bollgard® II is expected to occupy 70 to 80% of the 400,000 hectares of cotton in Australia.

9.11.3 China Case Study: Bt Cotton

Country Profile

Population	1.3 billion
Arable as % of total land	13%
Agriculture as % of GDP	18%
Agriculture as % employment	50%
Textile exports - (ranking)	$41.3 billion (#2)
Cotton area (ha)	4.8 million
Lint production (MT)	5.3 million
No. of cotton farmers	9-13 million

Introduction

China produces more cotton than any country in the world despite the fact that both India and the USA have larger areas of cotton. In 2001/02, China grew 4.8 million hectares of cotton with a high yield of 1,103 kg of lint per hectare to produce 5.3 million metric tons (MT), equivalent to 25% of world cotton production. China also consumes more cotton than any other country (5.4 million MT, equivalent to 27% of world consumption) and imported 100,000 MT compared with 50,000 MT of exports in 2000/01 (ICAC 2002a). Cotton is the most important cash crop in China but is subject to very heavy damage by the insect pest, cotton bollworm (*Helicoverpa armigera*). In the past, the area planted to cotton in China was as high as 6.7 million hectares, but severe damage due to cotton bollworm reduced this by 40% to about 4 million hectares in recent years. Loss due to cotton bollworm alone in 1992 (Jia 1998) was valued at the national level to be 10 billion RMB equivalent to US$1.2 billion (calculated at the official exchange rate of 8.27 RMB = US$1.00).

In the 1970s and early 1980s Chinese cotton farmers controlled bollworm and related pests with chlorinated hydrocarbons, such as DDT, until they were superceded by organophosphates in the mid 1980s (Stone 1998). Cotton bollworms developed resistance to organophosphates in the 1980s and to pyrethroids in the early 1990s, leading to very heavy but ineffective use of insecticides. Eventually, over-usage of insecticides resulted in unprofitability and led to a decline of cotton production in the more heavily infested bollworm areas in the Yellow River Valley. In the early 1990s, Chinese scientists initiated work on an alternative strategy of incorporating Bt as a transgene into cotton to confer resistance to cotton bollworm and related lepidopteran pests.

The Development of Bt Cotton

There are two developers and suppliers of Bt cotton in China. The first is the public sector Chinese Academy of Agricultural Sciences (CAAS) in collaboration with provincial academies and seed distribution organizations, and the second is Monsanto/ Delta Pine Land from the international private sector. CAAS developed a range of Bt cotton products under the aegis of the well-publicized 863 High-Tech Program. Work on the Bt gene was first undertaken at the Biotechnology Centre of the CAAS in Beijing.

By 1996 a total of 10 transgenic Bt cotton varieties had been developed and a total of 17 field trials were conducted occupying 650 hectares. In 1997, the Biosafety Committee of the Ministry of Agriculture approved commercialization of the first Bt cotton. The commercial plantings of the CAAS Bt cottons feature a modified Bt fusion gene, Cry1Ab/Cry1Ac, planted in the four provinces of Anhui, Shangdong, Shanxi, and Hubei (Jia 1998, James 1998). The cowpea trypsin gene, CpTi with a different mechanism of resistance compared to Bt, has also been incorporated as a stacked gene with Bt in some varieties. By 1999, the CAAS single gene Bt cottons, and the stacked Bt/CpTi cottons, designed to provide more durable resistance, were planted in nine provinces compared with four in 1998. It is estimated that at least 750,000 small farmers grew CAAS Bt cottons in 1999, most of which carried the single Bt gene. The single Bt cottons were planted in the nine provinces of Shangdong, Shanxi, Anhui, Jiangsu, Hubei, Henan, Hebei, Xinagjiang, and Lianoning. The CAAS cotton with stacked genes was planted in the four provinces of Shangdong, Shanxi, Anhui, and Hubei in 1999 (Jia 1999 personal communication). During 2000 and 2001 CAAS expanded its distribution and sales of Bt cotton varieties and currently has approval to sell 22 of its Bt cotton varieties in all the provinces of China. Governmental institutions have also developed new Bt cotton varieties by backcrossing the CAAS and other Bt varieties with their own locally adapted germplasm and these are being distributed and sold in many provinces.

The CAAS Bt cotton is being carefully monitored to develop the most effective means for achieving durable resistance within the context of a Bt management strategy. The Institute of Plant Protection has regularly sampled bollworms since 1997. Results indicate that field performance of Bt cotton is superior to non-Bt cotton with no indication that resistance to Bt is developing (Wu 2002). The multiple cropping system and the spatial distribution of Bt cotton planted on small farms in China surrounded by alternate host crops contribute to a natural “refuge.” Jia (1998) projects that the current cotton may provide adequate levels of resistance for up to 8 or 9 years from introduction in 1997, during which alternative strategies of control are being developed and implemented. One of the current alternative strategies being employed is the use of the Bt gene in conjunction with the *CpTi* gene, which encodes for an insecticidal protein with an independent mode of action from Bt. This strategy is being employed to provide better control and to delay resistance development.

The second supplier of Bt cotton in China is Monsanto/Delta Pine Land whose product is based on the variety 33B, which carries the Cry1A(c) gene. The product, which initially involved some collaboration with the Chinese, was approved for commercialization in 1997. However, unlike the Chinese Bt cotton, the Monsanto/Delta Pine Land product was initially grown in only one province, Hebei, with plans to expand to other provinces later. Approval is now in place for five Monsanto/Delta Pine Land Bt cotton varieties to be grown in the four provinces of Hebei, Shandong. Henan and Anuhi.

Taking into account the Bt cottons deployed by both CAAS and Monsanto/Delta Pine Land in China, there has been remarkable progress with both products since the Bt cottons were first deployed in 1997. Detailed and rigorous surveys have been conducted by an able team of Chinese and US members to assess the impact of Bt cotton in China. Surveys were conducted in 1999 (Huang et al 2002, Pray et al 2001), 2000 and 2001, and the five years of experience (1997 to 2001) with Bt cotton in China has been published (Pray et al 2002), and reported here.

Adoption of Bt Cotton

A multitude of public and private institutions, and companies are involved with Bt cotton development, distribution and sales in China, making characterization of adoption a challenging task. In addition, many farmers save seed, with both formal and informal seed-sales compounding the challenge of generating estimates of adoption. In practice, annual surveys of the kind conducted by Pray et al (2002) are the only practical means of generating an informative database to characterize adoption and assess the impact of Bt cotton on production. The surveys were initiated in 1999 involving 283 farmers in Hebei and Shandong provinces, expanded to include Henan Province in 2000, and further expanded to include Anuhui and Jiangsu in 2001. In several of these provinces cotton can suffer significant damage from bollworm and in provinces such as Hebei and Shandong adoption rates for Bt cotton quickly soared to 97% and 80% respectively in 2000, following their introduction in 1997.

The adoption rates for Bt cotton in China (Pray et al 2002) indicate that Bt cotton quickly escalated (Table 47) from less than 1% (<0.1 million hectares) in 1997, to 2% (0.1 million hectares) in 1998, 11% (0.4 million hectares) in 1999, 22% (0.9 million hectares) in 2000, and 31% (1.5 million hectares) in 2001. The initial 500,000 small farmers who adopted Bt cotton in 1998 derived significant and multiple benefits from the technology. Because farmers who adopted Bt cotton in 1998 were very satisfied with the experience, they were keen to continue the practice in 1999 and were joined by 1 million other small cotton farmers, which in turn led to the planting of 400,000 hectares of Bt cotton in 1999. This was equivalent to 11% of the Chinese national cotton area of 3.7 million hectares in 1999. The number of cotton farmers in China fluctuates annually, depending on the planted area of the cotton crop which ranged from 3.7 million hectares in 1999, to 4.8 million hectares in 2001 (Table 47). The estimated number of Bt cotton farmers in China has increased from a few thousand at its introduction in 1997 to 0.5 million in 1998, to 1.5 million in 1999, to 2.7 - 3 million in 2000, and 4 to 5 million in 2001 (Huang 2002). An important feature of Bt cotton in China is that it is produced by small farmers; the average cotton farm is less than one hectare and the cotton area less than 0.5 hectare. Contrary to popular opinion, government no longer

Table 47. Production of Bt Cotton in China, 1997-2001

Year	Cotton Area Ha Millions	Bt Cotton Area Ha Millions	Bt Cotton % of Area	Number of Cotton Farmers (Millions)	Number of Bt Cotton Farmers (Millions)
1997	4.5	<0.1	1	10.8	<0.1
1998	4.5	0.1	2	10.7	0.5
1999	3.7	0.4	11	8.5	1.5
2000	4.0	0.9	22	9.0	2.7 to 3.0
2001	4.8	1.5	31	13.0	4.0 to 5.0

Source: Pray et al., 2002. Huang, 2002, Personal Communication.

influences farm decisions re cotton production, and cotton quotas were discontinued by the government in 1998. Farmers themselves now decide whether or not to plant Bt cotton, and they buy seed and sell cotton in a competitive market where the price of cotton is not regulated by government as was the case up until 1999. The new Seed Law passed in 2000 allows private companies to conduct business directly with farmers. Thus, Chinese cotton farmers are no different to millions of small farmers who produce cotton in other developing countries like India, except that the farm size is smaller in China and their numbers are larger (Pray et al 2002). The number of cotton farmers in China ranges from 9 to 13 million, whereas India has 4 million cotton farmers, or approximately one-third of the cotton farmers of China.

Bt cotton now occupies about one third of the total cotton area in China. It is widely adopted in the Yellow River Valley where some provinces like Hebei are almost exclusively Bt cotton, 80% in Shandong, about 30% adoption in Anhui and Henan, and even small areas in the Northwest province of Xinjiang where bollworm infestation is much lower, and where cotton is grown under irrigation. Estimates of adoption are probably conservative, particularly for the last two years, when farmers have become increasingly aware of the value of Bt cotton, and save/sell more of their own seed and acquire it through many more formal and informal channels.

Impact on Insecticide Use

Data in Table 48 indicate that in all three years, insecticide usage was reduced substantially on Bt cotton compared with non-Bt varieties. The average saving in formulated insecticide was 43.8 kg/ha equivalent to a 67% reduction in insecticides. At a national level this translates to a reduction of 20,000 tons of formulated insecticide in 1999 and 78,000 tons in 2001. Expressed in terms of reduction of

Table 48. Insecticide Use on Bt and Non-Bt Cotton in China 1999-2001, Kg/Hectare of Formulated Product

	1999	2000	2001	Average
Non-Bt	60.7	48.5	87.5	65.5
Bt	11.8	20.5	32.9	21.7
Non-Bt - Bt	**48.9**	**28.0**	**54.6**	**43.8**

Source: Pray et al., 2002.

the number of sprays at the farm level in 1999, the number of insecticide sprays decreased from 20 sprays for non-Bt to 7 sprays for Bt – equivalent to a two-thirds reduction, a saving of 13 sprays. In 2000 the reduction in number of sprays were 12 (21 sprays reduced to 9), and 14 sprays (28 sprays reduced to 14) in 2001 (Huang et al 2002).

In 2001, China used an estimated 16,000 tons of cotton insecticides (a.i) valued at $285 million at the farm level (Wood Mackenzie 2002), down by more than 10 %, compared with 2000, which coincided with an almost 10% increase in Bt cotton adoption from 22% in 2000 to 31% in 2001. The cost savings, discussed later, associated with reduced volume of insecticides and the labor savings from reduced number of sprays is substantial and is the major element contributing to the overall economic advantage of Bt cotton in China.

Yield Advantage of Bt Cotton

Taking into account all farms in the survey in 2001, Bt varieties yielded about 10% more than non-Bt varieties – 3,481 kg/hectare versus 3,138 kg/hectare, a difference of 343 kg/hectare in favor of Bt cotton. This difference is somewhat higher than the 8% yield advantage reported for 1999. Yield advantage is also an important contributor to the overall economic advantage of Bt cotton. Because Bt is omnipotent throughout the season, and is more effective than sprays, Bt cotton provides superior control resulting in higher yields, even compared to the most intensive of insecticide spray programs.

Health Benefits Associated with Bt Cotton

According to the survey data (Pray et al 2002) the reduction in insecticide usage on Bt cotton compared with non-Bt cotton, was associated with a decrease in the percentage of farmers reporting that they had become sick from spraying insecticides. The information in Table 49 shows that in 1999, 22% of farmers growing non-Bt cotton reported ill-effects, compared with 5% for Bt cotton – a fourfold decrease in favor of Bt cotton. Similarly, in 2000 there was a fourfold decrease from 29% poisonings for non-Bt cotton to 7% for Bt cotton.

Table 49. Percentage of Bt and Non-Bt Cotton Farmers Suffering from Pesticide Poisonings in China 1999-2001

	1999	2000	2001
Non-Bt	22	29	12
Bt	5	7	8
Non-Bt - Bt	**17**	**22**	**4**

Source: Pray et al., 2002.

The difference was much lower in 2001 with non-Bt farmers reporting a 12% incidence of poisoning compared with 8% for Bt, 33% less poisonings for Bt cotton farmers. For the three year period 1999 to 2001 there was a consistent and significant decrease in the percentage of Bt cotton farmers suffering from pesticide poisonings, compared with non-Bt cotton farmers. In China, insecticides are applied to cotton with back-pack sprayers that are either hand or motor-powered. Given the demanding field conditions, avoidance of exposure to insecticides is difficult and the significant decrease in insecticide usage of 78,000 tons of formulated product in 2001 is a major achievement, not only in terms of health, but also in terms of the environment.

Economic Advantage of Bt Cotton

The data (Table 50) indicate that the overall economic advantage of Bt cotton, compared with non-Bt cotton ranges from $357/hectare in 1999 to $550 in 2000, to $502 in 2001, with an average of $470/hectare. It is noteworthy that in all 3 years, farmers growing non-Bt cotton were actually making a loss when labor is costed, whilst Bt farmers were enjoying substantial profits. To put economic advantage into context, in 1999 cotton farmers with an average per capita income of $250/annum were generating additional income of approximately $350/hectare equivalent to additional income of $140 for the average 0.4 hectare planting of Bt cotton. Considering that Chinese cotton farmers are small resource-poor producers, the Chinese experience with Bt cotton supports the thesis in the 2001 UNDP Human Development Report (UNDP 2001) that technology can contribute to the alleviation of poverty. In terms of distribution of benefits, the data clearly show that in 1999, 80 to 85% of total benefits accrued to farmers with a small percentage (15% to 20%) to the developers of the technology.

Taking all 3 years into account, savings on insecticides both in terms of lower cost for the reduced amount of product used and the substantial labor savings from reducing the number of sprays by one-half to two-thirds, is the major contributor to decreased production costs. The increase in yield of Bt

Table 50. Net Revenue (US$/Hectare) of Bt and Non-Bt Cotton Farmers in China 1999, 2000, 2001 (US$/Hectare)

	1999	2000	2001	Average
Bt	351	367	277	332
Non-Bt	- 6	- 183	- 225	- 138
Difference Bt/Non-Bt	**357**	**550**	**502**	**470**

Source: Pray et al., 2002.

cotton leads to increased revenue, which is offset by the higher price of Bt seed. For example, for 2001, labor savings, which are probably largely related to reduced number of insecticide sprays, provided savings of approximately $300, pesticide reduction approximately $100 savings, and increased yield $100 for a net economic advantage of $500/hectare. The additional cost of the Bt seed was approximately $60/hectare, whereas cost for fertilizer was higher for non-Bt cotton. Some critics voiced concern that Bt cotton would increase the supply of cotton and would result in losses rather than profits for Bt cotton farmers. Increased supply of cotton was associated with a significant price decrease of approximately 30% between 2000 and 2001 (4.42-4.45 yuan/kg to 3.02-3.04 yuan/kg). Despite this decrease in price, Bt cotton farmers still increased their income by approximately $500/hectare compared to non-Bt cotton farmers.

At a national level, the economic benefits of Bt cotton in China in 2001, based on adopted area of Bt cotton (Table 47) and net revenue/hectare (Table 50) was approximately $140 million in 1999, $495 million in 2000, and $750 million in 2001 (Table 51). Of this return of $1.4 billion over three years, about half, $700 million, can be attributed to the Bt cotton developed by the Chinese public sector (CAAS) which has invested R&D expenditures of the order of $100 million plus, annually on biotechnology for all crops, including cotton. This represents an excellent level of return on R&D investments for the Chinese Government and should provide the incentive to implement its intent to quadruple its R&D budget in crop biotechnology to $450 million by 2005. Bt cotton has also been an excellent investment for resource-poor small Bt cotton farmers in China who captured 80 to 85% of the total benefits in 1999. This represents a very high level of return for resource-poor small Bt cotton farmers who now suffer from less insecticide poisonings. It also represents an excellent investment for China as a nation, and for consumers who benefit from more affordable prices for cotton and a safer environment.

Table 51. National Economic Benefits Associated with Bt Cotton in China

Year	Benefits ($ Millions)
1999	140
2000	495
2001	750
Total	**1,385**

Source: Compiled by Clive James, based on data from Pray et al., 2002.

Highlights: China

- China is the biggest producer and consumer of cotton in the world. In 2001 production was 5.3 million metric tons (25% of world production), with an average high lint yield of 1,103 kg/hectare. Cotton is produced in China by up to 13 million small farmers, usually farming less than 0.5 hectares of cotton.

- Adoption of Bt cotton in China progressed very rapidly from its introduction in 1997 to 1.5 million hectares in 2001 (31% of the total cotton area). In 2001 it is estimated that between 4 and 5 million small farmers derived multiple benefits from Bt cotton.

- Based on survey data for 1999, 2000 and 2001, farmers have benefited from Bt cotton through: increased yields, up to 10%; from half to two-thirds reduction in the volume of insecticides used and labor required for their applications; reduced farmer exposure to insecticides leading to significantly fewer insecticide poisonings of farmers; substantive gains in income of approximately $500/hectare.

- At the national level, benefits from Bt cotton in China are estimated at $140 million for the 0.4 million hectares of Bt cotton planted in 1999, $495 million for 0.9 million hectares in 2000, and $750 million for the 1.5 million hectares of Bt cotton planted in 2001. For the three year period 1999 to 2001; the national benefit was $1.4 billion. Insecticide reductions at the national level were 20,000 tons in 1999, 25,000 tons in 2000, and 78,000 tons in 2001 of formulated insecticide.

- China benefits from the fact that there are two Bt cotton products offered to farmers; one from the public sector developed by the Chinese Agricultural Academy for Science (CAAS) and one from the private sector developed by Monsanto/Delta Pine Land. In 2001, between four and five million farmers made individual decisions re their preferred product and bought seed and sold cotton in the free market. Although increased supply of cotton from Bt cotton may have contributed to a 30% decrease in cotton prices between 2000 and 2001, Bt cotton farmers still increased their income by $500/hectare, when the average annual per capita income of many resource-poor cotton farmers was of the order of $250. This lends support to the thesis that technology can contribute to the alleviation of poverty as proposed by the 2001 UNDP Human Development Report.

- China recognizes the need to deploy Bt resistance in a responsible and effective strategy that optimizes the durability of the resistance. Accordingly, a Bt fused gene is being used in conjunction with the *CpTi* gene and a resistance monitoring system is in place to ensure early detection; no resistance has been detected since Bt cotton was first deployed in 1997.

- China has made a major public sector R&D investment in crop biotechnology, estimated at $112 million per annum in 1999. This is equivalent to more than half of all corresponding R&D expenditure on crop biotechnology in the developing world. China has further committed to increase its crop biotech R&D budget by 400% by 2005 to $450 million. Bt cotton is the first significant public sector Chinese GM crop product to be commercialized in China and has already paid handsome dividends. The China Bt cotton experience has important implications for other developing countries that grow cotton, such as India, which can derive similar benefits from Bt cotton and the other 15 GM food, feed and fiber crops which China is developing. There is an increasing body of evidence that GM crops can deliver agronomic, economic, environmental, health and social benefits to small resource-poor farmers, and society and contribute to food, feed, and fiber security and alleviation of poverty in developing countries.

9.11.4 India Case Study: Bt Cotton

Country Profile

Population	1.0 billion
Arable as % of total land	54%
Agriculture as % of GDP	27%
Agriculture as % employment	60%
Textile exports (ranking)	$8.5 billion (# 1)
Cotton area (ha)	9 million
Lint production (MT)	2.5 million
No. of cotton farmers	4 million

Introduction

Cotton is the leading plant fiber crop in the world and in India it is the most important fiber crop. India has a larger area of cotton than any other country in the world, approximately 9 million hectares (Table 52). This represents about one quarter of the world total cotton area and occupies 5% of India's total cultivated land area. However, cotton lint yield in India, averages only 233 kg/ hectare and is one of the lowest in the world. As a result of very low yields, cotton production in India represents only about 12% of total world production. It is estimated that the income of approximately 60 million people living in India is derived from the production, processing, and/or export of raw cotton and cotton textile goods (Bell and Gillham 1989). Some of the major constraints to cotton production in India are water availability at crucial stages of crop development, inadequate insect and disease control measures, low fertilizer inputs, and limited use of hybrid seeds.

Production, Distribution and Farm Size

India has addressed the need for increased cotton production under a series of 5-year plans. The strategy for increasing cotton production has several thrusts: accelerate the use of improved technology in both irrigated and rainfed areas, with emphasis on use of improved seed, optimum agronomic practices, and integrated pest management; cultivate more cotton in rice fallow and non-traditional areas; expand the irrigated area of cotton production; and increase the use of hybrid cotton. Targets for the 5-year plans have met with some success and India has graduated from being a large net importer of cotton, to being a modest importer and an exporter of a small tonnage of high-quality cotton suitable for spinning into higher count yarns. In 2000/01, India imported 450,000 MT and exported 34,000 MT (ICAC, 2002a). Today, cotton is grown in four regions in India encompassing the three states of Punjab, Rajasthan, and Haryana in the north; Maharashtra and Madhya Pradesh in the central region; Gujarat in the northwest coastal region; and Andhra Pradesh, Karnataka, and Tamil Nadu in the southern region. In the north, cotton is an important cash crop where approximately 95% of the crop is irrigated, and yields are generally higher than the other regions. The principal hybrids produce a short staple cotton suitable for spinning into 24 to 28 count yarns. In the central states, cotton is considered the most important cash crop. Even though some of the

Table 52. Land Holdings, Distribution and Production from Statistics of Cotton Farmers of India

Sr. No.	State	Average Size of Farm	Area of Cotton Ha (Millions)	Average Yield Kg/ha	Production Tons (Millions)	No. of Cotton Farmers (Millions)
1	A.P.	1.56	1.28	198	1.49	0.82
2	Gujarat	2.93	1.61	416	3.94	0.55
3	Haryana	2.43	0.58	255	0.87	0.24
4	Karnataka	2.33	0.61	239	0.86	0.26
5	Madya Pradesh	2.63	0.50	145	0.43	0.19
6	Maharashtra	2.21	3.20	139	2.62	1.45
7	Punjab	4.74	0.56	180	0.60	0.12
8	Rajasthan	4.11	0.64	230	0.87	0.15
9	Tamil Nadu	0.93	0.24	301	0.43	0.26
10	Others	-	0.07	-	0.07	-
	Total/Average		**9.29**	**223**	**12.18**	**4.04**

Source: Agricultural Statistics at a Glance, 2000. Published by Ag Statistics Division, Directorate of Ag & Co-operation, Mi Ref Table 3.17B, Page 47 & 243.

cotton production in the central area is irrigated, production depends largely on monsoon rains. The northwest coastal state of Gujarat is also dependent on monsoon rains for cotton production, because water salinity prevents extensive irrigation. The southern states are the most important from the standpoint of high quality cottons.

The distribution of cotton in India by state, farm size, area, yield, production, and number of farms is characterized in Table 52. The major feature of cotton-growing in India is that it is produced on relatively small farms by approximately 4 million producers. Farm sizes on which cotton is grown in India vary by state and range from an average farm size of 0.93 hectares in Tamil Nadu to 2.63 hectares in Maharashtra, which grows 35% of the national cotton area, to 4.7 hectares in the Punjab which grows only 6% of the cotton in India. The subsistence marginal farms that produce cotton in India are less than one hectare in size, whilst the small, semi-medium, medium and large are only 1 to 2 hectares, 2 to 5 hectares, 5 to 10 hectares, and >10 hectares, respectively. Thus, most of the cotton in India is produced by small farmers who are representative of the 4 million cotton farmers in the country. The average cotton holding in India is only just over 2 hectares. In terms of distribution by state, Maharashtra has by far the largest area of cotton (3.2 million hectares), with an average holding size of just over 2 hectares, followed by Gujarat (1.6 million hectares) and Andra Pradesh (1.28 Million hectares).

Insect Pests

The rationale for India's interest in Bt cotton is that cotton production is severely constrained due to damage by insect pests, particularly lepidopterans, which are the most important. The most serious pest is the American bollworm (*Helicoverpa armigea*), which can be very destructive, and is equally damaging to legumes, tomato, and several other crops. Annual losses caused by bollworm alone are estimated at approximately US$300 million (King 1994). Other important lepidopteran insect pests of cotton in India are the pink bollworm (*Pectinophora gossypiella*), spotted bollworm (*Earias vittella*), spiny bollworm (*Earias insulana*), and tobacco caterpillar (*Spodoptera litura*). To date, chemical control has been the most common practice and was often the only option. It is estimated that insecticides valued at $700 million are used on all crops annually in India, of which about 50% is used on the cotton crop alone (Dhar 1996). Many cotton farmers in India have committed suicide because of the heavy debt that they have incurred because of high expenditure on insecticides and the low international price of cotton. Because of heavy and indiscriminate use of all categories of insecticides, pests have developed resistance to most of the commonly used insecticides in the country. Conway (1997) reported that 450 pest species had developed resistance to one or more insecticides. Because of the undesirable effects of chemical insecticides, including the development of resistance to major pests, emphasis was placed on IPM where nonchemical crop management practices are used in conjunction with selective insecticides for insect pest control. Bt, with appropriate management, provides an effective alternative and environmentally superior control of bollworm and other lepidopteran insect pests of cotton (Wilson et al 1994, Luthy et al 1982).

Bt cotton was developed by the Maharashtra Seed Company (Mahyco) in which Monsanto has a 26% investment. The *Cry1A* (*c*) gene has been incorporated in hybrid cotton material and was approved for release in the environment in March 2002. Bt cotton with the *Cry1A (*c) gene has been tested in India for several seasons and three data sets are presented here for the period 1998 to 2001. While the data is not as comprehensive as is the case in countries where the products are grown on large acreage post-commercialization, there are some noteworthy trends apparent in the field trial data.

1) Department of Biotechnology Study, 1998/99

Extensive and fully replicated field trials of Bt cotton have been conducted under the guidance of the Department of Biotechnology of the government of India. These trials met

Table 53. Summary of Bt Cotton Trials Conducted in India, 1998-1999

Trial	Yield (Kg/Ha)	% Yield Increase Bt hybrids	No. of Bollworm Larvae/10 Plants		Fruiting Body Damage (%)	
			0-60 Days from Planting	61-90 Days	0-60 Days	61-90 Days
Set A Trials (15 Sites)						
Mean Bt hybrids	1,464	40	1.2	1.7	2.5	2.5
Mean non-Bt hybrids	1,045	-	6.1	6.4	8.7	11.4
LSD (0.05)	214	-	2.5	2.4	4.5	7.2
Set B Trials (25 Sites)						
Mean Bt hybrid	1,694	37	1.0	-	1.7	-
Mean non-Bt hybrid	1,238	-	7.9	-	9.0	-

Source: James, 1999 based on data provided by R. Barwale (personal communication, 1999).

the requirements of the government for release into the environment. Information from two sets of Bt cotton trials conducted in 1998-99 and 2000-01 are reported here (Barwale 1999, James 1999). Trial results are summarized in Table 53. Set A trials were conducted at 15 sites in seven Indian states in 1998-99 featuring six cotton hybrids, one containing the Bt gene, and one without Bt. Set B trials featuring one cotton hybrid (MECH-1) with and without Bt, were conducted at 25 sites in nine Indian states in *kharif* 1998-99.

Results from both studies indicate that Bt cotton hybrids significantly outyielded their non-Bt counterparts by 40% in Set A trials and 37% in Set B trials. Results confirm significantly less bollworm larvae on Bt cotton hybrids compared with their counterparts during the two periods 0-60 days (1.2 vs 6.1) and 61-90 days (1.7 vs 7.4) after sowing. Similarly, damage to fruiting bodies was significantly lower for Bt cotton hybrids compared with their counterparts in both sets of trials. Populations of sucking pests (aphids, jassids, and whitefly) and beneficial predators (ladybirds, green lacewing bug, spiders) were monitored in both Bt hybrids and non-Bt hybrids; no differences were noted between Bt hybrids and non-Bt hybrids. In Set B trials standard cotton cultivation practices were followed at each site including application of insecticides when the economic threshold levels for pests were exceeded. Application of up to seven insecticide sprays was necessary for non-Bt hybrids at all sites,

Table 54. Results of Field Trials and Economic Benefits of Bt Cotton in India

Country	1998-1999	2000-2001
Field Trial Results, Average for All Fields		
Yield (Kg/Ha)		
Bt	1,861 (37%)[1]	856 (38%)[1]
Non-Bt	1,359	619
No. of Sprays		
Bt	0	1
Non-Bt	4	4
Farmer practices	5-9	5-9
Economic Advantage Over Non-Bt	**$/Ha**	**$/Ha**
Yield increase	241 (79)	84 (27)
Pesticide cost reduction	45 (15)	42 (14)
Additional cost of Bt seed/ha[2]	50	50
Total Benefit	236 (77)	76 (25)
Benefits over farmer practices	255-278	88-142

Source of basic data: Naik (2001), ISAAA (2002b).

Note: [1] Figures in parenthesis are percentage over average net return from using non-Bt cotton.

[2] Bt cotton economic advantage data of Naik 2001 has been adjusted by $50/hectare to account for additional cost of Bt seed, compared with conventional seed; $50/hectare is based on actual seed prices in 2002 (Cost of 570 gms of Bt seed/acre was $30.39 compared with $10.39/acre for conventional seed; the premium for Bt cotton seed was $20/acre or $50 per hectare. Rs 48.5 = $1.00.

(average of four) whereas Bt hybrids required no sprays in most sites except two, where 1 to 3 sprays were applied.

2) The Naik Study: 1998/99 and 2000/01

Some of the same data from the multi-locational tests, discussed above, and conducted by the Department of Biotechnology in 1998/99 and 2000/01, were further analyzed by Naik (2001) with particular emphasis on assessing the potential economic advantage of Bt cotton in India. The results presented by Naik (2001) are summarized in Table 54 and for convenience discussed under the three topics of yield advantage, pesticide reduction and economic advantage.

Yield Advantage of Bt Cotton

In 1998/99 Bt cotton hybrids yielded 1,861 kg/hectare compared with 1,359 kg/hectare for corresponding conventional hybrids – a 37% yield advantage for Bt cotton. Similarly, in large scale field trials covering 85 hectares in 2000/01 Bt cotton hybrids yielded 850 kg/hectare versus 619 kg/hectare for conventional hybrids resulting in a 38% yield advantage for Bt cotton. Taking into account both years' data (1998/99 and 2000/01), the yield advantage of Bt cotton, compared with conventional, ranged from 24% to 56% in individual trials, with an average of 38% and an absolute yield advantage of 502 kg/hectare in 1998/99 and 237 kg/hectare in 2000/01 (ISAAA 2002b).

Reduction in Insecticide Use

In the 1998/99 field trials Bt cotton required no sprays at all whereas the conventional hybrids required 4 sprays (Table 54). Similar results for 2000/01 indicate that when only one spray was necessary for Bt cotton, four sprays were required for conventional cotton; a 75% reduction in insecticides for Bt cotton. However, it is important to note that the results from field experiments underestimate the actual reduction compared with the practice of farmers who apply up to twice the number of sprays, that are applied to conventional cotton in field experiments. On average farmers will apply 5 to 9 prophylactic insecticide sprays per season to control bollworm and other pests in their fields, compared with four sprays on conventional cotton plots in field experiments. In some regions in India such as Andra Pradesh and Karnataka where bollworm infestation is very high and resistance has developed to the cotton bollworm, farmers spray 15 to 18 times per season. Thus, in practice the potential insecticide savings with Bt cotton, for some farmers could be up to 75%, with an average reduction of at least 50%, from 7 sprays to 2 or 3 sprays.

Economic Advantage

The data in Table 84 indicate that the economic advantage from the yield increases associated with Bt cotton is relatively much greater than the cost advantage related to insecticide savings. Thus, in 1998/99 the cost advantage associated with increased yield was $241/hectare compared with $45 from insecticides; this is reflected in the 79% economic advantage for yield with Bt cotton compared with a corresponding 15% for insecticides in 1998/99. The same pattern is evident for 2000/01 trials which were atypical due to the late planting. At the time that the results of the trial were analyzed by Naik (2001), the additional cost for Bt cotton seed in India was not known. In the absence of prices for Bt cotton seed, Naik assumed that the additional cost for Bt seed would be $84/hectare (same as the US), but the effect of increased cost was only modeled and not included in the analysis of cost estimates published by Naik and reproduced in Table 54. Now, with the benefit of knowing the costs of Bt cotton seed that actually applied in India in 2002, the economic advantage estimates of Naik 2001 have been adjusted down by $50 per hectare for Bt cotton, which is the added cost/hectare of planting Bt seed, compared with conventional seed. Following these adjustments, the overall economic advantage of Bt cotton in 1998/99 was $236 per hectare, equivalent to about 77% gain, compared with conventional cotton. The corresponding figure for the atypical trials of 2000/01 was $76/hectare equivalent to about a 25% advantage over conventional cotton. The lower returns in 2001 were entirely due to the lower yield from later planting, with similar insecticide savings of $42/hectare in 2000/01, and $45/hectare in 1998/99.

The overall economic advantage of Bt cotton over farmer practices in 1998/99 was estimated to be in the range of $255 to $278/hectare, which is at the lower end of the corresponding estimates for China, which range from $350 to $550 per hectare. Naik (2001) also explored the effect of an 11% and 17% drop in the international price of cotton in the event that Bt cotton production would increase supply and reduce prices. Under the most pessimistic price scenario of a maximum 17% decrease in cotton prices, the benefits of Bt cotton over farm practices would be reduced in 1998/99 from ($255 to $278/hectare), to ($185 to $230/hectare), which still provides handsome returns to Bt cotton farmers.

3) The ICAR Cost Benefit Analysis Study

The last data set presented here for evaluating Bt cotton in India is the most recent information published by the Indian Council for Agricultural Research (ICAR). These field trials were conducted in 2001 by ICAR (ICAR 2002) in a project specifically designed to conduct a cost benefit analysis on Bt cotton. The results of the study are detailed in Table 55. Three Bt cotton hybrids, Mech 184, Mech 162 and Mech 12 were planted alongside a local check hybrid and a national check hybrid in a multi locational field trial in India. Pest infestation levels were high in India in 2001, which is the major factor impacting on the economic advantage of Bt cotton.

Yield Advantage of Bt Cotton

The data (Table 55) confirm that the Bt hybrids yielded from 60% to 90% more than conventional hybrids – the highest increases were recorded for Mech 184 up to 92%, followed by Mech 162, up to 87%, and Mech 12 Bt up to 60%. Yield increases of the same order of magnitude for the 2001 Kharif season were reported in a separate study (Qaim 2002). These are substantial increases in yield by any standard and provide a major contribution to the gross income increases generated by Bt hybrids. Gross income for the three Bt hybrids averaged 23,604 Rs/hectare ($487/hectare based on Rs 48.5 = $1.00) compared with 14,050 Rs/hectare ($290) per hectare for the local and national checks – a 68% gross income advantage for the Bt cotton hybrids over the conventional checks.

Insecticide and Pest Control Costs

Insecticide costs were highest for the local and national conventional check hybrids, which averaged 2,400Rs/hectare ($50) per hectare compared to $29/hectare for Mech 184, $29/

Table 55. Relative Agronomic and Economic Performance of Bt and Conventional Cotton in ICAR Field Trials in India in 2001

Entries	Yield (q/ha)	Gross Income (Rs/Ha)	Insecticide Control (Rs/Ha)	Additional Cost of Bt Seed/Ha[1]	Net Income[2] (Rs/Ha)	Difference[2] between Bt and Checks Rs/Ha
	(1)	(2)	(3)	(4)	(5) = 2-(3+4)	(6)
MECH 184 Bt	14.00	25,200	1,413	2,425	21,362	
Local Check	8.37	15,066	2,845		12,221	9,141
National Check	7.31	13,158	2,001		11,157	10,205
MECH 162 Bt	13.67	24,606	1,413	2,425	20,768	
Local Check	8.37	15,066	2,845		12,221	8,547
National Check	7.31	13,158	2,001		11,157	9,611
MECH 12 Bt	11.67	21,006	1,727	2,425	16,854	
Local Check	8.37	15,066	2,845		12,221	4,633
National Check	7.31	13,158	2,001		11,157	5,697

Source: ICAR, 2002. Personal communication. Report on 2001 IPM Trial Cost Benefit Analysis (RS 48.5 = US$1.00)

[1] Original data adjusted by subtracting $50/hectare for premium for Bt cotton seed compared with conventional seed. In 2002 cost of 570 gms of conventional seed/acre was $10.39 compared with $30.39/acre for Bt seed; This translates to a premium of $20 per acre for Bt seed or $50 per hectare.

[2] Adjusted for premium of $50/hectare for Bt cotton seed.

hectare for Mech 162 and $36/hectare for Mech 12 (Table 55). Insecticide savings at the farmer level are likely to be significantly greater because farmers often apply unnecessary insecticide applications as prophylactics. The average cost/hectare for pest control was $120/hectare (Table 56), ranging from $56 to $291/hectare and requiring from 6 to 16 sprays with an average of 10 sprays.

Economic Advantage of Bt Cotton

The additional cost of Bt hybrid seed versus conventional was not known at the time of the ICAR study. As for the Naik 2001 data set, the additional cost of $50/hectare for Bt hybrid seed, based on 2002 actual prices, has been used to adjust the ICAR data set. Despite this adjustment, the net incomes for the Bt hybrids are significantly higher than for national and local check conventional hybrids. Income is 38 to 46% higher for Mech 12, 70% to 77% for Mech 162, and 75 to 85% for Mech 184 (Table 57). The increase in net income for the Bt hybrids translate to increased profitability for the three Bt hybrids which are summarized in Table 57. This compares the economic advantage of each of the three Bt hybrids with

Table 56. Pest Control for Cotton in India, 1998-2001

State	Area of Cotton[1] Ha Millions	Pest Control Costs $/Ha	No. of Sprays
Karnataka	0.6	291	16
Punjab	0.6	131	10
A. Pradesh	1.3	128	12
Gujarat	1.6	124	13
Orissa	-	116	13
Tamil Nadu	0.2	87	7
Haryana	0.6	85	7
Rajathstan	0.6	56	7
Maharastra	3.2	59	6
Total/Average	**8.7**	**120**	**10 sprays**

Source: Modified from Pawar, 2002. [1] India Dept. of Agricultural Statistics. Exchange Rate: $1.00 = Rs 48.5 used for conversion.

the local/national check conventional hybrids. The data in Table 57 indicate that the economic advantages of Bt hybrids range from $96/hectare (4,633 Rs/hectare) to $210/hectare (10,205 Rs/hectare). It is noteworthy that the magnitude of the economic advantage is of the same order as the 1998/99 data set analyzed by Naik, 2001 ($236/hectare) and higher than the benefits in 2000/01 ($76/hectare) when late planting of trials led to atypical low yields. The data for the 2001 ICAR trials are also consistent with the 1998/99 Department of Biotechnology data set in that the major contribution to economic advantage is due to yield advantage, as opposed to insecticide product and labor reduction costs. However, the benefits in terms of farming practice can be expected to reflect a higher contribution from insecticide savings, because of the higher number of sprays applied by farmers (five to nine sprays or more), compared with up to four in field trials.

Summary

Some caution must be exercised with the India experimental data since the large acreage studies/surveys that are only possible after commercialization have not yet been conducted. Nevertheless, very encouraging results have been attained in the field trials conducted over several years. In summary, the three sets of field trial data present consistent data confirming that, compared with conventional hybrids, Bt cotton in India

Table 57. Economic Advantage of Bt Cotton Versus Conventional Cotton in India in ICAR 2001 Field Trials

Bt Hybrids	Local Conventional Check Hybrids		National Conventional Check Hybrids	
	Rs/Ha	(US$/Ha)	Rs/Ha	(US$/Ha)
Mech 184 Bt	9,141	**($188)**	10,205	**($210)**
Mech 162 Bt	8,547	**($176)**	9,611	**($198)**
Mech 12 Bt	4,633	**($96)**	5,697	**($117)**

Source: ICAR, 2002. Personal communication. Report on 2001 IPM Trial Cost Benefit Analysis (Rs 48.5 = US$1.00). Original data adjusted for $50/ha premium for Bt cotton seed, compared with conventional seed.

results in significantly higher yields, insecticide reductions, and increased profitability of $75 to $200/hectare or more for producers. The decrease in use of insecticides on Bt cotton could result in a 75% reduction for some farmers applying 10 to 15 sprays, but an average reduction of 50%, or more, from 7 to 2-3 sprays is more probable. This is a very significant potential saving given that in 2001, India used 21,500 metric tons of cotton insecticide (a.i) valued at $343 million, which is equivalent to 50% of all insecticides used in India on all crops. Bt cotton is also projected to result in significant environmental and social benefits, associated with: less insecticide pollution of the environment, soil and water; lower exposure of producers to insecticide and hence less poisonings; and continued low prices for cotton, which consumers will benefit from in terms of more affordable cotton and textile products. Given that India is a large producer of cotton, with 9 million hectares, the importance of providing effective control of bollworm has significant economic advantages and positive environmental implications for India and the textile industry.

Approval of Commercialization and Adoption of Bt Cotton in 2002

Following several years of successful field trials with Bt cotton, the Genetic Engineering Approval Committee (GEAC) of the Indian Government approved on March 26, 2002, the commercial cultivation of three Bt cotton Bollgard hybrids: Mech 12, Mech 162 and Mech 184, developed by Mahyco (Maharastra Hybrid Seed Company), in which Monsanto has a 26 % investment (Luce 2002). The GEAC approval is for 3 years and requires farmers to ensure a refuge of 20 per cent or 5 rows, which ever is greater, and for Mahyco to provide the seed for refuge and to monitor the development of insect resistance, if any, by generation of base line susceptibility data (Ramachandran, 2002).

The first commercial Bt hybrid cotton seed (three hybrids, Mech 12, 162 and 184, containing the *Cry 1 Ac Bt* gene) sold in India in 2002 was generated on 285 hectares planted with foundation seed by Mahyco, the company that has developed and registered the technology in India (Hindu 2002, Ramachandran 2002). On average, depending on yield, one hectare of foundation seed produced up to 100 hectares of certified seed. For the May/June Kharif season plantings in 2002, farmer demand for Bt cotton seed was very high and it is estimated that 44,500 hectares of certified Bt cotton was planted by 54,000 farmers, with an average of less than one hectare (0.82 ha) of Bt cotton per farm. In 2002 Bt cotton was planted in the six following states in India: Maharashtra, Karnataka, Andra Pradesh, Gujarat, Madhya Pradesh and Tamil Nadu. Bt cotton occupied approximately 0.5 % of the 8.7 million hectares of cotton in India in 2002, of which approximately half the area was planted to hybrids.

The seed was distributed by Mahyco and Monsanto directly to farmers in the Kharif 2002 season but in order to meet future high farmer demand, MMBiotech Ltd., a joint venture of Mahyco and Monsanto has also sub licensed this technology to other seed suppliers namely Raasi Seeds (Attur, Tamilnadu), Ankur Seeds (Nagpur, Maharashtra), Krishidhan (Jalna, Maharashtra), Ajeet Seeds (Aurangabad, Maharashtra), Emergent Genetics (Hyderabad, Andhra Pradesh) who will incorporate the gene in their own hybrids. In 2002 the seed was sold in packets containing 450 gms of Bt cotton seed and 120 gms of non Bt cotton seed sufficient to plant one acre of Bt cotton and required refuge at a price of $30.39 per packet. The corresponding non-Bt hybrid had a comparable price of $10.39 for a price premium of $20 per acre ($50 per hectare) for hybrid Bt cotton seeds. For the additional investment of $50 per hectare it has been established by trials that on average a farmer would generate an additional income of up to $200/hectare or more from cultivation of Bt cotton, equivalent to a 4:1 (200:50) return on investment. The additional income would be related to increased yield, savings on insecticides and labor costs for their application.

Farmers in the Aurangabad-Jalna cotton belt in India reported that they typically applied insecticide (organophosphates or synthetic pyrethroids) 10 to 15 times per season, depending on the infestation of bollworm. The cost of a single application of insecticide is estimated at approximately $12 per hectare for a total cost per hectare per season ranging from $120 (10 sprays) to $180 (15 sprays). For these farmers a reduction of between 4 and 5 sprays would pay for the additional cost of the Bt seed, with any further reductions contributing to profit that would also be generated from significant yield increases. It is estimated that 80% of the Bt cotton sales in 2002 were to farmers in villages near previous trial locations, where farmers had observed, at first hand, the improved performance of Bt cotton. It is projected that in 2003 there will be adequate seed supply to plant 285,000 hectares of Bt cotton, equivalent to approximately 3.5% of the national cotton area in India. Based on the Chinese experience with Bt cotton, where it already occupies one third of the national area, farmer satisfaction with Bt cotton in India could lead to a rapid escalation of adoption where more than half the cotton crop could be planted with Bt cotton in the future. The adoption rate for Bt cotton in India is likely to be similar or even higher than other countries that have adopted Bt cotton. Accordingly, it is feasible that subject to a successful launch in 2002, 25% of the cotton crop could be Bt cotton by 2005, and that eventually adoption rate will exceed 50%.

The Indian Council of Agricultural Research (ICAR) reported that the National Agriculture Research System is also developing hybrids of Bt cotton. Two genes have been successfully incorporated in three hybrids of Indian cotton at the Nagpur-based Central Cotton Research Institute and the University of Agricultural Sciences, Dharwar, Karnataka. It is projected that seeds of commercial quantity will be available in three years. Several of the major institutions in India including the Indian Council of Agricultural Research (ICAR), India Environment Ministry, and the Department of Biotechnology (DBT) strongly supported the decision to approve Bt cotton for commercialization. The Federation of Indian Chambers of Commerce and Industry (FICCI), observed that GM crops offer the potential for huge productive gains and that "if the kind of productivity increase seen in China, is possible in India, then genetically modified crops hold a lot of promise for Indian agriculture." The Federation believes that GM technology could help alleviate some of the challenges in increasing the productivity of Indian agriculture, the foundation of India's rural economy. Cotton accounts for approximately one-third ($8.5 billion) of India's total export earnings ($34 billion) either directly or indirectly through textiles and clothing, and thus has very important financial implications. The Indian Finance Minister, Yashwant Sinha, was very supportive of the commercialization of Bt cotton and has welcomed changes that result in "freedom for the farmer" and the lifting of outdated controls on the development of agribusiness (Luce 2002).

Highlights: India

- **Cotton area is approximately 9 million hectares, the largest in the world – this represents approximately one quarter of the global area of cotton of 34 million hectares. Cotton occupies 5 % of India's total cultivated area, and planted by 4 million small farmers. Its cultivation and processing provide income for approximately 60 million people.**

- **The cotton bollworm is the most serious pest of cotton in India with annual losses estimated to be at least $300 million. Insecticides valued at $700 million are used on all crops** annually in India, of which nearly 50% are used on cotton. Cost of the 21,500 metric tons (active ingredient) of cotton insecticides used in India in 2001 was $340 million.

- Results from extensive Bt cotton trials conducted from 1998 to 2001 confirm that Bt cotton, with the *Cry1 A*c gene provides effective and safe control of bollworm and related pests. Field trials have confirmed that, compared to conventional hybrids, Bt cotton can increase yields by up to 40% or more, reduce insecticide sprays by 50 % or more (from 7 to 2 or 3 sprays on average) equivalent to savings of $60/hectare, and increase overall farmer income from Bt cotton from $75 to $200 or more per hectare.

- Bt cotton was approved in India on 26 March 2002 and 44,500 hectares were planted by 54,000 farmers in May/June 2002. A successful launch in 2002 could increase Bt cotton to 285,000 hectares in 2003, and adoption could reach over 2 million hectares or 25% of total cotton area by 2005.

- Bt cotton has the potential to reduce the requirements for cotton insecticides in India by half, equivalent to over 10,000 tons of insecticide (a.i) annually at a cost of $170 million. Bt cotton can also have a positive impact on the environment, economics of production and productivity and the health of up to 4 to 5 million small farmers that grow cotton in India.

9.11.5 Mexico Case Study: Bt Cotton

Country Profile

Population	97.4 million
Arable as % of total land	13%
Agriculture as % of GDP	5.8%
Agriculture as % employment	23%
Cotton area (ha)	80,000
Lint production (MT)	92,000
No. of cotton farmers	3,000

Introduction

In 2001/02 Mexico grew 80,000 hectares of cotton with a high lint yield of 1,152 kg / hectare to generate a total production of 92,000 metric tons. Mexico consumed 403,00 tons of cotton lint in 2001/02 and had to import 383,000 tons; exports were minimal at 28,000 tons (ICAC, 2002a). The area of cotton in Mexico has declined from over 300,000 hectares in 1996 to less than 100,000 hectares today. Bt cotton was introduced commercially into Mexico in 1996. The two varieties of Bt cotton used in Mexico are NuCOTN 33^B and NuCOTN 35^B, with the *Cry1 Ac* Bt gene developed by Monsanto and Delta Pine Land. They are the same varieties introduced in the US in 1996. This case study is based on survey work conducted by Traxler et al (2001) and summarizes the impact of the introduction of Bt cotton in the region of Comarca Lagunera where survey information was collected from two farmer groups; the first group known as *ejitarios* with small farm sizes ranging from 2 to 10 hectares and the second group with larger farm sizes of 30 to 120 hectares. The mean size of surveyed cotton area /farm in 1997 was 15 hectares, and 8 hectares in 1998.

Distribution of Cotton and Adoption of Bt Cotton

Total area of cotton in Mexico has declined by 75% from about 315,000 hectares in 1996 to approximately 80,000 hectares in 2001 (Table 58). The significant decline in area is mainly due to low world cotton prices, which are now at their lowest historically at approximately $0.40 a pound. The decline in prices has been exacerbated by changes in government policy and recent limitations of irrigation water - 90% of the cotton area in Mexico is irrigated. Whereas total cotton area has decreased significantly during the last six years, the area of Bt cotton in Mexico has increased from 900 hectares in 1996, when it was first introduced, to a peak of 37,000 hectares in 1998 and occupied 28,000 hectares in 2001. The data in Table 58 indicate that Bt cotton as percentage of the total area of cotton in Mexico, has increased steadily from less than 1% in 1996 to 15% in 1998 to a maximum of 35% in 2001.

In 2000, about 80,000 hectares of cotton were grown in seven states of Mexico with the largest area in the state of Chihuahua, more than 25,000 hectares, representing more than 25% of the country's cotton area. The states of Baja California, Tamaulipas, Sonora, Coahuila, Durango and Sinaloa grew the balance of 55,000 hectares in 2000. Adoption rates of Bt cotton vary by state, and range from

Table 58. Bt Cotton Area and Percent Adoption in Mexico, 1996-2000

Year	Total Cotton Area (Ha)	Bt Cotton Area (Ha)	% Bt cotton area
1996	314,768	900	<1%
1997	214,378	15,000	7%
1998	249,602	37,000	15%
1999	144,995	17,000	12%
2000	79,581	26,106	33%
2001	80,000	28,000	35%

Sources: Traxler et al., 2001. 2001 data from Clive James, 2002.

a low of less than 10 % in Sinaloa and Baja California to 64 % in north Sonora to a high of over 95% in the region of Comarca Lagunera in the states of Coahuila and Durango, where the survey was conducted (Table 59) and where approximately 8,000 hectares of Bt cotton was grown in 2000.

The Importance of Cotton Pests

There are seven important insect pests that can cause damage to the crop in Mexico and result in economic losses. The most damaging are pink bollworm (*Pectinophora gossypiella*), boll weevil (*Anthonomus grandis*), tobacco budworm (*Heliothis virescens*) and cotton bollworm (*Helicoverpa zea*). Fall armyworm (*Spodoptera exigua*), white fly (*Bemisia argentifolii*), and conchuela (*Chlorochroa ligata)* can also cause crop damage and may require treatment in some areas in particular years. The infestation levels of the major lepidopteran insect pests, for which Bt cotton confers control, vary significantly from state to state, and patterns of infestation levels and economic losses vary widely across the main growing regions. The pests of importance in Comarca Lagunera are pink bollworm, cotton bollworm and tobacco budworm; boll weevil has recently been eradicated in the region. Bt cotton is very effective in controlling pink bollworm, provides good control for tobacco budworm, is sometimes less effective for cotton bollworm, and is only partially effective against fall armyworm. Pest infestation levels, particularly of boll weevil and pink bollworm, have fallen during the 1990s in Comarca Lagunera and the government has supported pest monitoring, post harvest control of cotton residue, and has subsidized the adoption of Bt cotton. An active biological control program has released approximately 40 million eggs of the beneficial insect *Trichograma spp.* against budworm and *Crysoperla spp.* against white fly.

Table 59. Area Planted to Bt Cotton by State, Mexico 2000

State or Region	Total Cotton Area (Ha)	Bt Area (Ha)	Percent Bt
Comarca Lagunera	8,263	7,932	96%
North Chihuahua	22,000	8,387	38%
South Chihuahua	4,500	1,500	33%
North Sonora	2,248	1,445	64%
South Sonora	5,500	1,270	23%
Baja Calif.	14,500	1,110	8%
Tamaulipas	11,741	4,332	37%
Sinaloa	1,177	130	7%
Total Mexico[a]	**79,581**	**26,106**	**33%**

Sources: Traxler et al., 2001. [a] Includes states not listed in table.

Yield Advantage of Bt cotton in Mexico
The yield advantage of Bt cotton when infestation was low in 1997 was 0.04 metric tons/hectare, equivalent to 3%, and 0.29 metric tons/hectare, equivalent to 20% in 1998 when infestation was higher (Table 60). The yield advantage of Bt cotton is related to the infestation level of pink bollworm and cotton bollworm which were relatively low in 1997 and high in 1998.

Reduction in Use of Insecticides
The data in Table 61 indicate a consistent decrease in the number of insecticide sprays applied to Bt cotton compared with non-Bt cotton which also resulted in decreased cost due to less product and labor savings. In 1997 there was a saving of 2.26 sprays resulting in a cost advantage of $154/hectare. Similarly, in 1998 there was a saving of 3 sprays at a cost of $139/hectare. No estimates of cost savings were available for 1999 and 2000 but again Bt cotton required 2.5 less sprays in 1999 and 1.0 spray less in 2000. Thus, over the four year period 1997 to 2000, the number of insecticide sprays required by Bt cotton was approximately half of that required on non-Bt cotton, resulting in an average number of 2.2 less insecticide sprays at a cost saving of approximately $150 per hectare in 1997 and 1998.

Economic Advantage of Bt Cotton
Bt cotton was grown on 52% of the cotton area in 1997 in Comarca Lagunera and pest infestation was relatively low compared to

Table 60. Lint Yield (Mt/Hectare) of Bt Cotton and Non-Bt Cotton in Mexico, 1997 and 1998

	1997 Mt/Ha	1998 Mt/Ha
Bt	1.58	1.71
Non-Bt	1.54	1.42
Difference Bt/Non-Bt	**0.04 (3%)[1]**	**0.29 (20%)[1]**

Source: Traxler et al., 2001. [1]Difference expressed as % of non-Bt yield.

Table 61. Number and Cost of Insecticide Applications on Bt Cotton and Non-Bt Cotton in Mexico

	1997		1998		1999	2000
	# Sprays	$/Ha	# Sprays	$/Ha	# Sprays	# Sprays
Non-Bt	5.24	259	4.60	200	6.0	3.0
Bt	2.98	105	1.55	61	3.5	2.0
Non-Bt - Bt	**2.26**	**154**	**3.05**	**139**	**2.5**	**1.0**

Source: Traxler et al., 2001, Sanchez Arellano, 2000, ISAAA, 2002c.

1998. Although Bt cotton yielded slightly more than non-Bt cotton the latter was graded slightly higher in 1997, resulting in a slightly lower return of $49/hectare for Bt cotton. This was offset by substantially lower insecticide costs of $154 for Bt cotton, which had higher seed cost ($61/hectare). Overall, this resulted in a small economic advantage of $44/hectare for Bt cotton in 1997 compared with non-Bt cotton (Table 62).

In 1998, Bt cotton occupied 72% of the cotton area in Comarca Lagunera. The results for 1998, when pest infestation was higher than 1997, exhibit a significantly greater economic advantage ($543/hectare) attributed to yield which was 20% higher, as opposed to 3% in 1997. Cost savings for insecticide were $139/hectare which were offset by higher Bt cotton seed cost of $56/hectare, resulting in an overall economic advantage for Bt cotton of $626 per hectare. It is noteworthy that the higher yield of Bt cotton was the major contributor ($543) to the overall economic

Table 62. Economic Advantage ($/Hectare) of Bt Cotton and Non-Bt Cotton in Mexico, 1997

1997	Bt $/Ha	Non-Bt $/Ha	Difference Bt - Non-Bt $/Ha
Yield	2,712	2,761	- 49
Insecticide	105	259	+ 154
Seed Cost[1]	101	40	- 61
Balance			**+ 44**

Source: Traxler et al., 2001. [1] Includes technology fee.

advantage of $626 for Bt cotton (Table 63). There was a large degree of variation in the performance of Bt and non-Bt cotton between 1997 and 1998, reflecting relatively low levels of pest infestation in 1997 compared with 1998 when they were high but not severe.

In 1997 and 1998, Bt cotton farmers gained about 3% and 20 % respectively in yield. Insecticide sprays were decreased by half in both years, for a saving of about two sprays resulting in a cost saving of about $150/ hectare. Although the cost of Bt seed was about $60 more than non-Bt, the cost savings for Bt cotton, due to less insecticide and higher yields, which generated higher revenues, resulted in an economic advantage of $44/ hectare in 1997 and $626/hectare in 1998.

Distribution of Benefits

It was estimated (Falck-Zepeda et al 2000b) that Bt cotton in Mexico in 1997 and 1998 resulted in an economic surplus of more than $6 million of which 86% went to Bt cotton farmers and 14% to the developers of the Bt cotton. Whereas Bt cotton farmers in 1997 and 1998 benefited $335/hectare on average, the developers of the technology gained less than $100 per hectare.

Concluding Comments

The combined effect of the eradication of the boll weevil, use of Bt cotton and the reduced cotton area has resulted in a dramatic fall in the use of chemical insecticides in the Comarca Lagunera region of Mexico. Per hectare insecticide use has fallen by more than 80%, from an average of nearly 14 kgs/ hectare of active ingredient in the 1980s to about 2 kgs/hectare. The large difference in relative profitability of Bt cotton between 1997 and 1998 is probably largely due to differences in pest infestation levels. The yield advantage of Bt cotton increases in parallel with higher infestation levels; 1997 was a low year for pink bollworm compared to 1998. By historical

Table 63. Economic Advantage ($/Hectare) of Bt Cotton and Non-Bt Cotton in Mexico, 1998

1998	Bt $/Ha	Non-Bt $/Ha	Difference Bt - Non-Bt $/Ha
Yield	3,123	2,580	+ 543
Insecticide	61	200	+ 139
Seed Cost[1]	87	31	- 56
Balance			**+ 626**

Source: Traxler et al., 2001. [1] Includes technology fee.

standards, even 1998 was not a heavy pink bollworm year. With more than $600/hectare net benefit during years of high infestation, and slightly higher profits in low pest years, Bt cotton provides growers a valuable insurance against pest infestation. The profit from 1998 alone will cover the additional cost for Bt cotton seed for several years.

Cotton production in the Comarca Lagunera region has undergone a transformation over the past decade. The most notable changes are a reduction in insecticide use and the corresponding reduction in the cost of production. The result has been increased yields and profitability and competitiveness, and a reduction in the risk associated with cotton production failures from insect infestations. A number of factors have been important, including the availability of Bt cotton varieties, and government support for farm credit and integrated pest management. Bt cotton varieties have made an important contribution to the region's control of pink bollworm, which would not have been possible without the new technology. At an average of about two insecticide applications per season, cotton has now become a profitable and low insecticide crop, benefiting both farmers and residents of the region. Bt cotton varieties have been a very appropriate useful technology for the Comarca Lagunera region. Bt cotton only protects against lepidopteran pests and has lower adoption in other Mexican states, where lepidopteran pests are less important. Cotton production in Comarca Lagunera is intensive; 95% of cotton is irrigated, yields are high by world standards, infrastructure is well developed, and material, financial and other inputs are readily available. All of these factors have favored the very high adoption of Bt cotton. Of particular importance in Comarca Lagunera were the key government interventions of credit for financing the purchase of Bt cottonseed combined with technical assistance for small landholders, and the implementation of an effective integrated pest management program.

Highlights: Mexico

- **Mexico grows from 80,000 to 300,000 hectares of cotton annually; international price of cotton is the main determinant of the annual cotton area. In 2000, 35% of the 80,000 hectares grown was Bt cotton.**

- **A study was conducted in 1997 and 1998 to assess the impact of Bt cotton in the Comarca Lagunera region. Bt cotton required between 2 and 3 fewer insecticide sprays, at an average reduced cost of $150/hectare.**

- **Cost of Bt seed was $60/hectare higher than non-Bt cotton.**

- **Overall economic advantage of Bt cotton was dependent on pest infestation level. For 1997 when pest infestation was low the economic advantage was $44/hectare and $626/hectare in 1998 when infestation was higher. The major portion of the gains in 1998 was associated with yield advantage, $139 from pesticide reduction offset by approximately $56/hectare for increased cost for seed, for a net economic benefit for Bt cotton of $626/hectare.**

- **Farmers were the major beneficiaries of Bt cotton for 1997 and 1998 when an economic surplus of $6 million for the 12,500 hectares was generated, of which 86% went to farmers and 14% to the developers of the technology.**

9.11.6 Argentina Case Study: Bt Cotton

Country Profile

Population	36.6 million
Arable as % of total land	9%
Agriculture as % of GDP	5.7%
Agriculture as % employment	8%
Cotton area (ha)	152,000
Lint production (MT)	50,000
No. of cotton farmers	Approx. 10,000

Introduction

In 2001/02 Argentina grew 152,000 hectares of cotton with an average lint yield of 328 kg/hectare for a total production of 50,000 tons of lint (ICAC 2002a). Cotton area in Argentina fluctuates with the international price of cotton and has declined from around 750,000 hectares in 1998/99 to 150,000 hectares in 2001/02. Bt cotton developed by Monsanto and Delta Pine Land, with the *Cry1Ac* gene, was successfully field tested in Argentina and approved for commercialization in 1998 (James 1998). Most of the cotton in Argentina is grown in two provinces in the north east, in Chaco and Santiago del Estero, which together grow almost 90% of the crop. Cotton is grown on large farms, greater than 90 hectares, which account for 70% of production, on small farms that account for 21% of production, and on the smallest farms, called *minifundios* (less than 20 hectares) which account for 9% of cotton production. The total number of cotton farmers in Argentina in 2000/01 was approximately 10,000 (Qaim 2002). Two studies have been conducted to assess the economic impact and to characterize the adoption of Bt cotton and the results are summarized in this case study (Qaim and de Janvry 2002, Elena 2001).

Insect Pests of Cotton

The major cotton insect pests in Argentina that can be controlled with Bt are cotton bollworm (*Helicoverpa armigera*), tobacco budworm (*Heliothis virescens*), cotton leafworm (*Alabama argillacea*) and the pink bollworm (*Pectinophora gossypiella*). The two Bt cotton varieties, incorporating the *Cry1Ac* Bt gene, NuCOTN 33^{B} and DP 50B have been released in Argentina.

Adoption of Bt Cotton

Bt cotton was introduced in 1998 with a small hectarage of 5,500 hectares equivalent to 0.7% of the total 750,930 hectares (Qaim and de Janvry, 2002). The area of Bt cotton increased from 5,500 hectares in 1998 to 12,000 in 1999 (3.6% of cotton area), to 22,000 hectares in 2000 (5.4%) and was static at 5% in 2001/02 (Table 64). These adoption figures are consistent with those reported by James (1999, 2001a).

Comparison between the performance of Bt cotton and non-Bt cotton

The data in Table 65 for yield, insecticide usage, cost of seed and overall economic advantage for Bt cotton and non-Bt cotton are averages for the two seasons, 1999/2000

Table 64. Adoption of Bt Cotton in Argentina, 1998-2001

	Cotton Area (Ha)	Bt Cotton Area (Ha)	%
1998-1999	750,930	5,500	0.7
1999-2000	331,890	12,000	3.6
2000-2001	409,950	22,000	5.4
2001-2002	169,000	9,000	5.3

Source: Qaim and de Janvry, 2002.

Table 65. Comparison Between the Performance of Bt Cotton and Non-Bt Cotton in Argentina 1999-2000 and 2000-2001

	Yield Kg/Ha	No. of Insecticide Sprays	Insecticide Cost $/Ha	Seed cost $/Ha	Gross Margin $/Ha
Non-Bt	1,567	4.8	37.40	17	80
Bt	2,110	2.5	19.93	103	100
Difference	543 (35%)	2.3	17.47	86	20

Source: Qaim and de Janvry, 2002.

and 2000/2001, derived from the data reported by Qaim and de Janvry (2002). A significant and consistent yield advantage of approximately 35% was generated by Bt cotton compared with non-Bt cotton (Table 65). The results from the survey conducted in 1999/2000 (Elena 2001) also report an increased yield of 907 kg/hectare for Bt cotton.

Non-Bt cotton on average required 4.8 sprays, compared with 2.5 sprays on Bt cotton, i.e. 2.3 fewer insecticide sprays. Compared with conventional cotton, in 1999/00, Bt cotton required 2.1 sprays compared with 4.5 sprays, for a difference of 2.4 fewer sprays, and in 2000/01, 2.8 sprays compared with 5.1 for non-Bt cotton, for a difference of 2.3 fewer sprays (Qaim 2002). On average Bt cotton required half the number of sprays. The data in Table 65 show a decrease of approximately 50% in cost of insecticides on Bt cotton, compared with non-Bt which translated to an economic gain of approximately $17.50/hectare. Elena (2001) also reports a corresponding gain of $27.55 in favor of Bt cotton in 1999/00 due to reduced insecticides.

The cost of Bt cotton seed was $103/hectare compared with $17/hectare for conventional seed; a six fold difference in price equivalent to approximately $85/hectare (Table 65). Data from the survey conducted in the same areas in 1999/00 (Elena 2001) estimated the difference in price between Bt cotton and non-Bt cotton at $75/hectare which is slightly lower, but in the same range.

Gross margin advantage for Bt cotton was estimated at an average of $20/hectare, with considerable variation between 1999/00 and 2000/01.The lower gross margins for Bt in 2000/01, ($5/hectare) compared with 1999/00 ($36/hectare), were influenced by the lower price of cotton in 2000/01 and higher input costs. Elena (2001) reported a gross margin of $65 per hectare in favor of Bt cotton for 1999/2001.

Concluding Remarks

Given that the lepidopteran insect pests which lend themselves for control by Bt are important in Argentina and that Bt farmers benefit from increased yield, decreased cost of insecticides and higher net returns, the issue of why adoption of Bt cotton has stagnated at 5% deserves to be addressed (Qaim and de Janvry 2002). There is limited awareness of the benefits of Bt cotton, particularly amongst small farmers (less than 20 hectares). However, Qaim and de Janvry (2002) conclude that the major constraint to adoption is the high price ($103/hectare) of Bt cotton seed, compared with $17/hectare for non-Bt cotton seed. For the average cotton grower they note that the high price of Bt cotton seed can more than double farmer expenditure for all purchased inputs. They conclude that a price of $103 is equivalent to a $78 technology fee, which is similar to the USA, but pest infestation levels in Argentina are generally lower than in the USA, leading to lower returns in a cotton-growing system which is subsidy-free and lower-cost than the USA. For all these reasons, the value of Bt cotton is lower in Argentina than the USA and hence Qaim and de Janvry suggest that it may be appropriate to consider pricing Bt cotton seed at a lower level than the USA, as is done in Mexico (Traxler et al 2001). A simulated demand curve for Bt cotton in Argentina indicated that the optimal price for both farmers (at a 40 to 50% adoption rate) and the developers of the technology would be a price of about $40 to $50/hectare for Bt seed (Qaim and de Janvry 2002).

Highlights: Argentina

- **Cotton area in Argentina has declined from 750,000 hectares in 1998 to approximately 150,000 in 2001, as international prices have decreased to historical lows in 2001/02.**

- **Bt cotton was introduced into Argentina in 1998, but adoption has stagnated at 20,000 hectares or less, equivalent to 5% adoption rate.**

- **On average, Bt cotton increases yield by about 35%, or around $100/hectare and decreases insecticide use by 2 sprays or $17/hectare. The price of Bt seed is $85 more than non-Bt seed, thus resulting in an average net benefit to Bt cotton farmers of around $20/hectare in 1999/00 and 2000/01.**
- **A simulated demand curve for Bt cotton suggests that the optimal price for Bt cotton may be $40 to $50/hectare, which would increase adoption rates to 40 to 50% and reward both farmers and the developers of the technology with optimal returns.**

9.11.7 South Africa Case Study: Bt Cotton

Country Profile

Population	42.1 million
Arable as % of total land	12%
Agriculture as % of GDP	4.5%
Agriculture as % employment	9%
Cotton area (ha)	44,000
Lint production (MT)	19,000 (2001/02)
No. of cotton farmers	4,000 (3,600 small and 400 large commercial farmers)

South Africa

Cotton area in South Africa fluctuates from year to year and can range from 40,000 hectares to 100,000 hectares or more. In 2001/02 South Africa grew 44,000 hectares of cotton, with an average yield of 430 kg lint/hectare for a total production of 19,000 metric tons (MT). In 2001/02 South Africa consumed 72,000 tons of lint and had to import 40,000 tons, twice the amount it produced (ICAC, 2002a). The cotton area in 2001/02 was lower than the previous year because low international prices of cotton led farmers to plant maize and sunflower, which were perceived to be more profitable.

Cotton is produced in South Africa under irrigated and rainfed agriculture. In 2001/02 there was a total of approximately 10,000 hectares of irrigated cotton and 22,000 hectares of rainfed (Table 66). Cotton is grown in 5 major regions: the largest irrigated areas are in Mpumalanga, Northern Province, Northern Cape and Orange River, whereas cotton is produced on rainfed/dry land in Northern Province, KwaZulu Natal and the North West.

Approximately 95% of cotton production is produced by approximately 400 large commercial farms and 5% by about 3,600 small farmers. In 2000/01 approximately 400 large commercial farmers produced 157,515 bales of cotton, whereas 3,300 small farmers in the Makhathini Flats and 300 small farmers in the Tonga region produced the balance of 7,300 bales. Several surveys have been conducted in the Makhathini Flats in KwaZulu Natal to characterize cotton production by small farmers who first adopted Bt cotton in 1998 (Ismael et al 2002, Kirsten et al 2002, Ismael et al 2001). Cotton production by small farmers in the Makhathini Flats has been promoted by the Vunisa cotton company which provides extension advice, inputs and manages credit. It is projected that eventually up to 4,500 farmers could produce cotton in the Makhathini Flats on up to 30,000 hectares of some of the best land in South Africa and contribute up to 30% of total cotton production in South Africa. The profile of a typical small scale farmer in the Makhathini Flats is a 40 plus year old man (52% of farmers) or woman (48% of farmers) farming 2.5 to 5.0 hectares of land, on which he/she grows less than 2 hectares of cotton as the principal crop (Ismael et al 2001), which is the major source of income for these resource-poor farmers. The

Table 66. Cotton Production in South Africa 2001-2002 Production Year

Area	Hectares Irrigation	Hectares Dry Land
Mpumalanga	4,322	0
Northern Province	3,071	12,515
Northern Cape and Orange River	1,214	0
KwaZulu Natal	620	6,843
North West	224	2,747
Total	**9,451**	**22,105**

Source: Kirsten et al., 2002.

bollworm complex is the major insect pest constraint in South Africa, which can cause severe damage and economic losses, for which Bt cotton offers good protection.

Adoption of Bt Cotton

The Bt cotton with the *Cry1 A(c)* gene developed by Monsanto/Delta Pine Land was field tested and introduced commercially to South Africa in 1998 with some pre-commercial areas planted in 1997 (Thomson 2002, James 1998). The area of Bt cotton has increased from 12,000 hectares in 1998 (10% adoption) to 20 to 30,000 hectares (45% adoption) by 2001/02. However, the striking feature about Bt cotton adoption in South Africa is the high adoption rate by small farmers in the Makhathini Flats and in the Tonga area. The number of farmers growing cotton in the Makhathini Flats increased from 75 in 1998 to 2,976 in 2001 (Table 67). Similarly, hectarage of Bt cotton increased from 80 hectares in 1998 to 5,670 hectares in 2001. The data in Table 67 for the Makhathini Flats confirm the very high rate of adoption from under 10% adoption of Bt cotton in 1998 to approximately 40% in 1999, 60% in 2000, and 92% in 2001. Adoption in the Tonga area was also at more than 95% in 2001(Kirsten et al 2002).

Yield Advantage of Bt Cotton

The yield advantage of Bt cotton for small farmers (49%), and large farmers under both irrigated (19%) and dry land (14%) conditions is consistent (Table 68). Surveys of small farmers (Ismael et al 2001) showed variable results in 1998/99 and 2000, with an average increase in yield of 24% over the two year period with a corresponding benefit of 29% in gross margins (Table 69). Another data set reports increases of 27 to 48% in yield of Bt cotton over non-Bt cotton (ISAAA 2002d). The yield advantage of Bt cotton will be mainly

Table 67. Area of Bt Cotton and Number of Bt Cotton Farmers in the Makhathini Flats, South Africa 1998-1999 to 2000-2001

	Bt Hectares	No. of Small Farmers	Adoption % Bt
1998-1999	80	75	10
1999-2000	752	411	40
2000-2001	1,864	1,184	60
2001-2002	5,670	2,976	92

Source: Bennett, 2002 and Ismael et al., 2002a.

Table 68. Yield Advantage (Kg/Hectare) of Bt Cotton Versus Non-Bt Cotton for Small and Large Farmers on Irrigated and Dry Land in South Africa

	Small Farmers	Large Farmers	
		Dry Land	Irrigated
Bt	576	947	4,046
Non-Bt	395	832	3,413
Difference Bt/Non-Bt	**181 (49%)**	**115 (14%)**	**633 (19%)**

Source: Kirsten et al., 2002.

Table 69. Advantages of Bt Cotton, Makhathini Flats, South Africa 1998-1999 and 1999-2000: Yield, Pesticide Use, Seed Cost and Gross Margins

Yield	+ 24%
Pesticide Savings	+ 32%
Seed Cost	- 67%
Gross Margin	+ 29%

Source: Ismael et al., 2001.

determined by the level of infestation of the bollworm complex; the higher the infestation, the greater the yield advantage with a gain of 25% to 50% being fairly representative over the last few years.

Reduction of Pesticide and Labor Requirements

The most recent and detailed data set for 32 small farmers in the Makhathini Flats in 2002 (Ismael et al 2002a) show that insecticide sprays were reduced by 7 sprays, from 11 to

Table 70. Savings Associated with Fewer Insecticide Sprays and Less Labor on Bt Cotton in South Africa, 200-2001

	No. of Sprays	Cost $/Ha
Non-Bt	11	70
Bt	4	25
Difference Bt/Non-Bt	**+ 7**	**45**

Source: Ismael et al., 2002a. Cost of one insecticide spray, including labor is RSA 66.85 ($6.50) at RSA 10.5 = $1.00

Table 71. Incidence of Insecticide Poisonings and Data on Adoption of Bt Cotton in the Makhathini Flats in South Africa 1997-1998 to 2000-2001

	1997-1998	1998-1999	1999-2000	2000-2001
Incidence of insecticide poisonings	51	30	14	6
% of Bt Cotton adopted	0.1%	10%	40%	60%

Source: Ismael et al., 2002a.

4 sprays when using Bt cotton (Table 70). The corresponding cost savings from the reduced insecticide spray program was $45/hectare, with insecticide costs for non-Bt at $70/hectare and $25/hectare for Bt cotton. It is noteworthy that it takes one day for a person to spray one hectare of cotton, which involves 9 km of walking and the application of 120 liters of water which has to be carried over several kilometres. This saving of time for both men, women and children has important social implications. For example, half the farmers are women, who can use the time saved more profitably for household activities, caring for children, the sick, and other off-farm activities.

Health Implications - Reduced Insecticide Poisonings

Data on insecticide poisonings were obtained from hospitals in the Makhathini Flats where Bt cotton is grown, for a four year period starting in 1997/98 when Bt cotton was first introduced. The data covers the months of December to March, which coincide with insecticide spraying of cotton. The data in Table 71 indicate that there is a negative correlation between the incidence of insecticide poisonings and the percent adoption of Bt cotton. Thus, in 1997/98 when the % adoption of Bt cotton was only 0.1%, incidence of insecticide poisoning cases were

Table 72. Economic Advantage (US$/Hectare) of Bt Cotton Versus Non-Bt Cotton for Small and Large Farmers in South Africa

	Small Farmers	Large Farmers	
	Dry Land	Dry Land	Irrigated
Yield	+ 47	+ 30	+ 60
Reduced Insecticides	+ 3	+ 11	+ 28
Increased Seed Cost	(-15)	(-22)	(-54)
Advantage/(Disadvantage)	**+ 35**	+ 19	+ 34

Source: Modified from Kirsten et al., 2002.

51. When Bt cotton adoption rates increased from 10% to 40% and 60% from 1998/99, to 1999/00, to 2000/01, the corresponding incidence for insecticide poisonings decreased from 30, to 14, to 6, respectively. Whereas this data provides an indication that there may be a relationship between the adoption of Bt cotton and insecticide poisonings, more research needs to be conducted to establish a causal relationship.

Overall Economic Advantage of Bt Cotton

Yield advantages for Bt cotton, coupled with insecticide and labor savings which are partly offset by higher seed costs, result in an overall economic advantage of the order of $50/hectare for small Bt cotton farmers in the Makhathini Flats (ISAAA 2002d). Increased seed costs for Bt cotton for small farmers can range from $8 to $15/hectare. The data of Ismael et al 2001, report Bt cotton seed at $20/hectare and non-Bt cotton at $12/hectare; a premium of $8 for Bt cotton seed. Data in Table 72 indicate that the premium for Bt cotton seed is $15/hectare for small farmers and can be as high as $54 for large farmers. The data in Table 72, which excludes savings in labor costs, show that Bt cotton provides an economic advantage of $35/hectare for small farmers, and ranging from $19 to $34/hectare for large farmers under rainfed and irrigated conditions respectively. Adjusting the data in Table 72 for savings in labor costs would result in an overall economic advantage of $40 to $50/hectare; the magnitude of the economic return will vary by year and be principally dependent on the infestation level of the bollworm complex.

Highlights: South Africa

- **South Africa grows 30,000 to 100,000 hectares of cotton per year. The planted area is influenced by the international price of cotton and planting conditions; cotton is grown under irrigated and dry land farming systems.**

- About 95% of cotton production is produced by 400 commercial farmers, whereas the balance of 5% is produced by about 3,300 small farmers in the Makhathini Flats and 300 small farmers in the Tonga area.

- Bt cotton was first grown in 1998 and the hectarage is now 20,000 hectares or more, representing about 45% of the cotton area in 2001.

- Many surveys have been conducted in the Makhathini Flats of KwaZulu Natal to assess the impact of Bt cotton on small farmers. In 2001, 2,976 small farmers grew 5,670 hectares, representing 92% of the cotton area in the region.

- Small farmers growing Bt cotton in the Makhathini Flats gained through increased yields of 25% or more, decreased number of insecticide sprays (from 11 to 4 – a saving of 7 sprays), reduced pesticide costs ($45/hectare) and suffered less insecticide poisonings; the higher cost of Bt seed (up to $15/hectare for small farmers) resulted in an overall economic advantage of up to $50/hectare for Bt cotton. The time saving associated with fewer sprays has important social implications allowing women farmers (approximately 50% of farmers) to spend more time with family, caring for children, the sick and household activities.

- Bt cotton offers many advantages to the communal growers in the Makhathini Flats and Tonga regions of South Africa: less exposure and handling of insecticides; reduced probability of utilizing contaminated insecticide containers for drinking water; reduced contamination of wells and water sources with insecticides; lighter labor load for men, women and children involved in the arduous and hazardous task of insecticide spraying, leaving more time for important family household activities that are currently suffering from inadequate attention.

9.11.8 Indonesia Case Study: Bt Cotton

Country Profile

Population	207 million
Arable as % of total land	10%
Agriculture as % of GDP	20%
Agriculture as % employment	43%
Textile exports (ranking)	$3.8 billion (#3)
Cotton area (ha)	22,000
Lint production (MT)	9,000

Introduction

In 2001/02, Indonesia grew 22,000 hectares of cotton with an average lint yield of 386 kg/hectare and a national production of 9,000 MT. Indonesia can only meet about 2% of its significant consumption of 525,000 MT of cotton from domestic production and has to import the balance of 98% at significant cost of around $500 million (ICAC 2002a).

Adoption of Bt Cotton

One of the major cotton-growing provinces of Indonesia is South Sulawesi, which produces about one-third of the cotton grown in Indonesia. The local varieties suffer from heavy infestations of lepidopteran pests and require up to 12 applications of insecticide per season, which is hazardous to producers and the environment. Following testing in containment facilities and multilocational field trials, the Indonesian government approved Bt cotton for commercial production in South Sulawesi in 2001; approximately 4,000 hectares of Bt cotton were planted and government officials and farmers were encouraged with the results (Manwan and Subagyo 2002, ISAAA 2002e).

Information from Indonesia confirms that Bt cotton has provided effective control of the major cotton pests, resulting in significant increases in yield, decrease in insecticide use (Table 73), and has contributed to higher incomes and profits for farmers. In 2001, Bt cotton with the *Cry 1 A(c)* gene yielded 30% more than the best local varieties and required only 0 to 3 applications of insecticide compared with 9 to 12 for local varieties. Cotton farmers in Indonesia normally spend 60% of their production costs on insect pest control and the saving in insecticides and higher yields have increased farmers' income significantly.

Highlights: Indonesia

- **Bt cotton is the first GM crop for Indonesia to commercialize in 2001. Preliminary information confirms that Bt cotton provides effective control of the lepidopteran insect pests that cause significant economic loss.**

- **Bt cotton has increased yield by about 30% and requires only 0 to 3 applications of insecticide compared with 9 to 12 for non-Bt varieties, and has increased farmers' income due to higher yields and saving on insecticides.**

Table 73. Performance of Bt Cotton in Indonesia, 2001

	Yield MT/ha	No. of Sprays
Bt	2.37	2
Non-Bt	1.82	10
Difference	0.55	8

Source: Manwan and Subagyo, 2002 and ISAAA, 2002e.

- **Indonesia can only produce 2% of its cotton requirements and has to import 500,000 MT per year of cotton, at a cost of $500 million to meet its fiber requirements. Bt cotton can contribute to increased domestic production of cotton resulting in less reliance on imports and contribute to a safer environment and less health hazards to producers.**

9.12 Agronomic, Environmental, Social and Economic Benefits

Bt cotton provides significant multiple benefits to producers and society (Qaim and de Janvry 2002, Ismael et al 2002a,b,c, 2001, Carpenter et al 2002, Gianessi et al 2002, ISAAA 2002a,b,c,d,e, Huang et al 2002, Pray et al 2002, 2001, Naik 2001, Benedict and Altman 2001, Edge et al 2001, Perlak et al 2001, Traxler et al 2001). These benefits result in significant agronomic, environmental, social and economic advantages. The benefits are realized by growers through: increased yields; reduced production costs; environmental benefits from reduced use of broad spectrum synthetic insecticides; health benefits from using a safer form of insect control; and social benefits that arise from increasing incomes while saving valuable time for farmers and their families, particularly in developing countries. The principal agronomic, environmental, social and economic benefits are discussed as well as the secondary benefits that derive from them.

9.12.1 Agronomic Benefits

9.12.1.1 Yield advantage and improved pest control

The major agronomic attribute of Bt cotton over conventional cotton is its ability to produce significantly higher yields in the presence of infestations of the major lepidopteran pests. This reflects Bt cotton's higher level of resistance conferred by Bt genes, particularly to the bollworm complex. Higher yields, plus decreased insect control costs are usually the principal contributors to the increased profitability of Bt cotton. Given that pest infestations vary significantly from country to country and year to year, yield advantage of Bt cotton would also be expected to be highly variable. The data in Table 74 list the average increases in yield (expressed as a percentage of the corresponding non-Bt yield) in eight countries that have approved and now grow Bt cotton commercially. It is evident that the yield increases are highly variable and there are several features that deserve comment.

Acknowledging that to-date results are based only on field experiments, it is notable that India, a country situated in the tropics, has reported some of the highest average increases in yield associated with Bt cotton. Naik (2001) has reported an average increase of 38%; similar high increases in yield have been consistently reported for extensive multi-year, multi-locational field trials in India. In 2001 when cotton insect pest infestation was severe in India, yield increases in experiments were exceptionally high, up to 90% (ICAR 2002). On the contrary, China, a temperate country which also suffers from heavy pest infestations that sometimes require up to 28 to 30 sprays per season, has consistently reported more modest yield increases of 5 to 10% (Pray et al 2002, 2001). Yield increases for China are slightly lower than the US where the average increase is estimated at about 10% or more (Benedict and Altman 2001). Finally, Australia which

Table 74. Global Yield Increases (%) in Bt Cotton in Selected Countries

Country	% Yield Increase[1]
India	38
Argentina	35
Indonesia	30
South Africa	24
Mexico	11
USA	10 +
China	5 to 10
Australia	Not significant

Source: Compiled by Clive James, 2002.
Data from Country Case Studies in this publication.
[1] Increase over Non-Bt.

Table 75. Increase in Lint Production due to Bt Cotton in USA

	MT
1998	80,740
1999	117,935
2001	84,085

Sources: Carpenter and Gianessi, 2001; Gianessi et al., 2002.

normally has to apply 10 or more sprays to control heavy infestations has reported no significant increases in yield over the four year period, 1996/1997 to 1999/2000 (Fitt 2002 In Press). More detailed information on yield increases for specific countries are found in the country case studies on pages 85 to 136 of this publication.

The literature is replete with confirmations that Bt cotton provides improved pest control of the major lepidopteran pests resulting in significant increases in yield (Carpenter et al 2002, Pray et al 2002, Ismael et al 2002a,b,c, Benedict and Altman 2001, Edge et al 2001, Traxler et al 2001). In the US alone, Bt cotton increased lint production by 80,704 MT in 1998, 117,935 MT in 1999 and 84,085 MT in 2001 for a total of 282,724 MT more lint for a three year period (Gianesi et al 2002, Carpenter and Gianessi 2001) Table 75. In the US in 2001 the increase in lint due to Bt cotton was valued at $115 million, equivalent to about 3% of the total annual production of lint in the US, valued at about $4 billion. In China, the increase in seed cotton (which is about three times the weight of lint) for 1999 was 80,000 MT on 0.4 million hectares and 514,00 MT on 1.5 million hectares in 2001.

9.12.2 Environmental Benefits

9.12.2.1 Reduction in use of cotton insecticides

Bt cotton has resulted in a significant decrease in the number of insecticide sprays required for the control of the major Lepidopteran insect pests. In turn, this reduction has had a major impact on the total number of insecticide sprays applied to Bt cotton. As expected, the reduction in the number of sprays is related to the degree of infestation which varies significantly in different seasons and countries.

The listing in Table 76 indicates that the highest recorded reduction on a national basis was for China in 2001 when the number of sprays required by Bt cotton decreased by half, from 28 sprays to 14 sprays, a saving of 14 sprays.

Indonesia has reported a decrease from 10 to 2 sprays for a saving of 8 sprays (ISAAA 2002e), and South Africa a decrease from 11 to 4 sprays for a saving of 7 sprays on the small farms in the Makhathini Flats (Ismael et al 2002a,b,c). Conventional cotton in Australia usually requires 10 or more sprays, and for Bt cotton, the number of sprays has been reduced on average from 11.2 to 6.5 for a saving of 4.7 sprays (Fitt 2002/In Press). Other sources report that cotton growers in Australia benefit from significant reductions ranging from 27% to 61% with an average reduction of 43% or 7.7 fewer sprays per hectare (Betz et al 2000). Prior to commercialization of Bt cotton in India in 2002, data from a large number of multilocational trials indicated that on average, Bt cotton would reduce the need for insecticides from 7, to 2 - 3 sprays, for a saving of 4 - 5 sprays. In Mexico, the average number of insecticide applications was reduced by 42% in 1999 and 33% in 2000 (Sanchez-Arellano 2000) and Traxler et al (2001) also reported a decrease from 5 to 2 - 3 sprays for Mexico. Argentina (Qaim and de Janvry 2002) reported a reduction from 5 sprays to 2 - 3 sprays, for a saving of 2 - 3 sprays. In the US the savings associated with Bt cotton have been estimated at 2.2 sprays (Benedict and Altman 2001). Taking into account the scope and scale of the reduction in the number of insecticide sprays in eight countries that grow Bt cotton, it can be concluded that on average the number of sprays has been reduced by at least half, with the absolute reduction ranging from 2 to 14 sprays. This is a significant reduction with enormous implications in terms of the environment, health, water savings, economics and the social impact on the lives of small farmers in developing countries.

Table 76. Estimated Reduction in Number of Insecticide Sprays for Bt Cotton in Selected Countries per Season

Country	Reduction # of Insecticide Sprays
China	Up to 14
Indonesia	Up to 8
South Africa	Up to 7
Australia	Up to 7
India	Up to 5
Mexico	Up to 3
Argentina	Up to 3
USA	Up to 2

Source: Compiled by Clive James, 2002 from various sources and Country Case Studies in this publication.

In terms of absolute volume of insecticide savings, the largest savings are for China and the US because they have large Bt cotton areas. For China, the saving of 14 sprays in 2001 was equivalent to a corresponding saving in amount of formulated insecticide of 54.6 /kg/hectare [from 87.5kg/hectare (non-Bt) to 32.9kg/hectare (Bt)], for a national saving of 78,000 tons of formulated insecticide (Pray et al 2002, Huang et al 2002). In 2000, the number of sprays required by Bt cotton in China also decreased by almost two thirds from 21 to 9 sprays, a saving of 12 sprays. The corresponding saving in amount of insecticide was 28.0/kg/hectare [from 48.5kg/hectare (non-Bt) to 20.5kg/hectare (Bt)] for a national saving of approximately 25,000 tons of formulated insecticide. For China in 1999 the number of sprays required by Bt cotton again decreased by two thirds from 20 to 7 sprays, a saving of 13 sprays; the corresponding saving in amount of insecticide was 48.9/kg/hectare from 60.7kg/hectare (non-Bt) compared with 11.8kg/hectare for Bt. The data of Pray et al (2002) indicate that Bt cotton in China alone reduced insecticide usage by 20,000 tons of formulated insecticide in 1999 on 0.4 million hectares, 25,000 tons in 2000 on approximately 0.9 million hectares, and 78,000 tons in 2001 on approximately 1.5 million hectares, for a three-year total savings of 123,000 tons of formulated insecticide (Table 77). In summary, for the three period 1999 to 2001 in China, the annual average saving in cotton insecticide due to the use of Bt was 13 sprays equivalent to 44.7 kg/hectare of formulated insecticide for a total substantial savings of 123,000 MT of formulated insecticide for the three year period.

These savings in insecticide are substantial by any standard and will increase as area of Bt cotton increases, especially in large highly infested cotton-growing countries like India. Further, insecticide savings will also occur in countries such as Australia and the US as new technologies, such as Bollgard® II, are introduced that will provide more effective control of the major lepidopteran and other pests and a broader spectrum of the secondary pests. The highest savings per hectare associated with reduced need for insecticides have been reported for China, up to $300/hectare, followed by Mexico $150/hectare, USA ($50/hectare), South Africa ($45/hectare), Australia ($20/hectare) and Argentina ($17/hectare); savings are also likely to be significant in India from 2002 onwards.

Table 77. Reduction in Use of Cotton Insecticide in China 1999, 2000 and 2001

Year	Reduction in # of Sprays	Saving in Insecticide Kg/Ha	National Saving in Insecticide MT Formulated
1999	13	48.9	20,000
2000	12	28.0	25,000[1]
2001	14	54.6	78,000
Total/Avg	**Avg 13**	**Avg 44.7**	**Total 123,000**

Source: Pray et al., 2002a. [1]Estimated from data.

The global cotton insecticide market, measured in metric tons (MT) of active ingredient (a.i.), was estimated at 81,200 MT for 2001 (Wood Mackenzie 2002). Of the countries that grew Bt cotton in 2001, the major cotton insecticide markets were China 16,000 MT, the USA 12,000 MT, and Australia 1,200 MT; combined, they represented over one third (36%) of the global cotton insecticide market of 81,200 MT in 2001. The US market is atypical at this time in that a large portion of the market, up to 75% in 2000, is related to the eradication campaign for boll weevil. However, this is not a confounding factor in the calculation of Gianessi et al (2002) who estimated a saving of 848 MT (a.i.) of insecticides due to the cultivation of 2.08 million hectares of Bt cotton in the US in 2001, 1,224 MT in 1999 and 907 MT in 1998 (Carpenter and Gianessi, 2001) for a three year total of 2,979 MT (a.i.) of cotton insecticides. Note that the US insecticide savings are in active ingredient (a.i.) and that the China estimates are in formulated product, so they are not comparable.

Benedict and Altman (2001) estimated that in the US, a reduction of 2.2 insecticide sprays on 1.1 million hectares of Bt cotton resulted in elimination of 1.09 million kg (1,090 MT) of insecticide active ingredient (a.i.) in 1998; this calculation is based on 0.45 kg/hectare of a.i. per single spray/hectare. This quantity, 0.45 kg/hectare is comparable to the amount of active ingredient often applied per spray/ hectare in developing countries, where the number of sprays is usually much higher than the US because of significantly higher pest infestations, pest-conducive tropical or sub-tropical climates, and where inefficient control programs often have to cope with severe problems related to insect resistance to insecticides.

The 0.45 kg/a.i./hectare/spray calculation used by Benedict and Altman (2001), to estimate the savings in insecticide (active ingredient), can also be utilized to generate estimates of insecticide savings for the major Bt cotton countries in 2001 by multiplying 0.45kg x the reduction in number of sprays x the Bt cotton hectarage. Thus, for Australia in 2001, the estimated saving in insecticides (a.i.) is 0.45 kg x 5 sprays x 146,000 hectares of Bt cotton = a saving of 329,000 kg (329 MT) of active ingredient insecticide. The total estimated amount of insecticide applied to cotton in Australia in 2001 was 1,200 MT a.i., and thus the estimated saving of 329 MT is equivalent to 27 % of the 1,200 MT or 22% of 1,660 MT (1,200+329) that would have been used if Bt cotton was not available (Table 78).

A similar estimate for China generates a saving of 9,450 MT in 2001 compared with an estimated market for all cotton insecticides in China of 16,000 MT (Wood Mackenzie 2002). The saving of 9,450 MT is equivalent to 61% of the 16,000 MT of cotton insecticides used in China in 2001, or 37% of the 25,450 MT that would have been necessary had Bt cotton not been available. Three countries grew 98% of the 4.3 million hectares of Bt cotton in 2001. The US grew 60%, China 35% and Australia 3% with the balance of 2% in the other four countries, Indonesia, Mexico Argentina and South Africa. Taking the estimated savings of 329 MT for Australia, the 9,450 MT for China

Table 78. Estimates of Insecticide Reductions (MT of a.i.) Associated with Bt Cotton in 2001, based on 0.45 Kg a.i. per Hectare/Spray

Country	Insecticide Reduction MT a.i.	Insecticide Usage MT a.i.	% 2001 Usage
China	9,450[1]	16,000	61
USA	848[2]	2,720[2]	31[4]
Australia	329[3]	1,200	27
Others	<100	300	-
Total	**10,627[5]**	**20,220**	**13%[5]**

Source: Compiled by Clive James 2002. [1]Based on reduction of 14 sprays at 0.45 kg a.i./ha/spray

[2] Estimate of Giannessi et al, 2002.

[3] Based on reduction of 5 sprays @ 0.45 kg a.i./ha

[4] Total usage in US is 10,800MT of which an estimated 8,080 MT is malathion for bollweevil eradication, with the balance of 2,720 MT used for other pests (usda/nass 2002).

[5] Reduction of 10,627 MT expressed as % of 81,200 MT, (13%) of global cotton insecticides in 2001.

and 848 MT for USA (Gianessi et al 2002), the estimated total savings of insecticide (a.i.) on Bt cotton in 2001 was of the order of 10,627 MT. This is equivalent to 13% of the 81,200 MT (a.i.) of all insecticides used on cotton globally in 2001 (Wood Mackenzie 2002).

There are several important secondary benefits that have implications from reducing the amount of insecticides applied to cotton. These include:

9.12.2.2 Less insecticides in aquifers and the environment

The substantial decreases in insecticides associated with the cultivation of Bt cotton, 78,000 MT less formulated insecticides in China in 2001, and 848 MT of insecticide (a.i) in the US, lead to significant decreases in insecticide run off into watersheds, aquifers, soils and generally into the environment. Whereas the insecticides that are currently approved meet maximum toxicity requirements of regulatory bodies, many insecticides have lethal effects on non-target organisms, and aquatic animals in ponds and streams (Edge et al 2001). This is of particular concern in developing countries where monitoring is not undertaken to detect pollution of natural resources.

Several recent studies in the US have used computer models, used by EPA, to study the potential effects of commercialization of transgenic crops on water quality in aquifers and watersheds. Predictions suggested that the substitution of conventional insecticides with Bt cotton would impact positively on water quality. Some initial experiments to monitor water quality have confirmed the predictions that transgenic crops have the potential to have a significant positive impact on water quality. The following studies are underway:

- The computer model predictions of Estes et al 2001, suggest that the substitution of conventional insecticides by Bt cotton, Bt corn and herbicide tolerant corn is likely to impact positively on water quality by significantly reducing pesticide concentrations in ground and surface water.

- A monitoring study on Bt cotton in the Mississippi Delta (Cullum and Smith 2001) has confirmed computer predictions that, compared with conventional cotton, the level of pyrethroid insecticides was substantially lower in Bt cotton plantings.

9.12.2.3 Farmer exposure to insecticide and health implications

Chemical insecticides used in cotton have high toxicity to humans (USEPA 2001). Conversely, the insecticidal protein produced in Bt cotton has been deemed to pose “no foreseeable human health hazards” (USEPA 1998). The replacement of the chemical insecticides with Bt cotton has clearly reduced the risks to farm workers and to others in the farm community who may be exposed (Betz et al 2000). These effects are particularly important in regions of the world where modern application techniques are not always adopted or are even available for use. The World Health Organization (WHO) reported an estimated 500,000 insecticide poisonings per year resulting in 5,000 deaths (Farah 1994). Whereas caution is advised in interpreting these statistics (Yudelman et al 1998), the practice of insecticide application can be hazardous if precautions are not taken. Even in industrial countries, where farmers normally take the necessary precautions, non-adherence to recommended practices for the safe and effective use of insecticides leads to insecticide poisonings amongst farmers. The Environmental Protection Agency (EPA) in the US estimates that US agricultural workers suffered between 10,000 and 20,000 insecticide poisonings a year (Phipps and Park 2002).

Surveys in South Africa (Rother 1998) confirm that due to lack of awareness, inadequate protective clothing and the necessary training, women farmers in the Makhathini Flats in South Africa often mixed insecticides with their hands, discarding surplus insecticide carelessly so that it contaminated domestic water supplies. The women also collected spray-contaminated edible weeds from cotton fields sprayed with insecticides. The health benefits of Bt cotton are especially beneficial for women and children as it precludes direct exposure (women and children actively participate in the spray program), but also reduces contamination of water utensils, as discarded insecticide containers are often reused for carrying water (Ismael et al 2002a,b). These reports and others (Repetto and Baliga 1996, Rola and Pingali 1993) confirm the widespread risk that farmers are exposed to, particularly in developing countries, where insecticides are applied under difficult and hazardous conditions.

Surveys of Bt cotton in China from 1999 to 2001 have consistently shown that on average the incidence of insecticide poisonings for farmers using Bt cotton is up to four times less than farmers using conventional cotton, which requires up to 28 insecticide sprays per season (Pray et al 2002). There is also circumstantial evidence from South Africa that the use of Bt cotton results in a decrease in insecticide poisonings (Ismael et al 2002a).

The Plant Industry has long recognized the need to mount educational/training programs to promote the safe and efficient use of crop protection products. Crop Life International has expanded these activities and currently, training in safe use of insecticides is being conducted in more than 70 countries (Crop Life International 2002).

9.12.2.4 Reduced production risks and enhanced opportunities to grow Bt cotton

Given that Lepidopteran pest infestations are one of the principal contributors to low and unstable yields, Bt cotton significantly reduces the production risks for cotton farmers, to which they assign very high priority. This is particularly important when international cotton prices are low and when damage from pest infestations can make a difference between a profit and a loss.

Some locations pose restrictions to the use of conventional cotton. These restrictions may be related to unusually heavy pest infestations and/or the presence of insecticide resistant strains making cotton-growing unprofitable. For example, in the Yellow River region of China, cotton production decreased from around 3 million tons in 1991 to 1.4 million tons in 1993, because the bollworm infestation level was so high that it became unprofitable to grow cotton. In 1999, the land that had formerly been precluded from cotton production because of bollworm infestation was replanted to Bt cotton and farm levels of cotton production were restored in the Yellow River region (Pray et al 2002). Similarly, prior to the introduction of Bt cotton in the US in 1996, areas in the southern states of the USA had abandoned growing cotton because of severe problems with pink bollworm (Edge et al 2001). There are similar areas where pest pressures have precluded the commercial production of cotton in other cotton-growing regions of the world (Benedict 1996). Restrictions related to the proximity of bodies of water (lakes, rivers) or leisure areas (parks) and residential areas, where spraying of insecticides would be limited or unacceptable, may also apply. ReJesus et al (1997) confirm that location of cotton field and other factors, including distance from the farm, type of soil, and use of irrigation, impact and constrain the farmer's decision to plant conventional cotton, which requires multiple sprays. For example, heavy clay soils do not lend themselves for spraying because soils become wet and difficult to traverse. Similarly, if the crop is irrigated, pipes have to be dismantled and reconnected requiring additional labor. Bt cotton requiring none or only a few sprays means that these constraints do not apply or they become less limiting. In summary, Bt cotton provides farmers much more flexibility and is subject to less constraints, and therefore impacts positively on the future economic outlook for the cotton industry, providing more stability as well as decreasing production risk, which is of critical importance to cotton growers worldwide.

9.12.2.5 Increased populations of beneficial insects

The use of broad spectrum insecticides, such as pyrethroids, on cotton has adversely affected and decreased the populations of non-target species including the arthropod natural enemies that can provide effective control of non-lepidopteran pests. Prior to the introduction of the Cry1Ac gene in Bt cotton in 1996, there was speculation that given the insecticidal specificity and effectiveness of the Bt proteins (English and Slatin 1992) used as topical sprays that arthropod natural enemies would be protected, increase in numbers, and have the potential to act as biological control agents and thus contribute to integrated pest management. Experimental studies confirmed that the arthropod natural enemy populations in Bt cotton are greater than in non-Bt cotton (Roof and DuRant 1997). In addition to reducing the number of sprays for the bollworm/budworm complex in the US, Bt cotton has also reduced the number of sprays for other insects such as thrips and aphids, by one or two sprays (Benedict and Altman 2001). This effect has been attributed to higher populations of beneficial predators and parasitic insects, that are depleted or eliminated by broad spectrum insecticide sprays.

There is evidence to indicate that significantly higher populations of economically important predatory bugs, spiders and ants are found in Bt cotton fields in comparison with fields treated with conventional insecticides (Head et al, In Press a). Beneficial insects appear to help control cotton pests in Bt cotton when the beneficial populations are not suppressed by insecticide sprays (Smith 1997). These data on beneficial populations all lend support to the thesis that Bt cotton can be effectively used as a building block for the foundation of an Integrated Pest Management strategy in cotton. There is increasing evidence from large scale studies of commercial Bt and conventional cotton in the southern US in 2000 that higher numbers of arthropod natural enemies are found in Bt cotton fields, compared with non-Bt cotton fields (Head et al, In Press a). The results confirm that Bt cotton provides a more favorable environment for species such as *Geocovis*, *Orius*, spiders and ants which act as biological control agents for control of secondary pests in Bt cotton fields. Similar effects have been reported in Bt cotton in China (Xia et al, 1999), where there was a significant reduction in number of broad spectrum insecticide sprays following the introduction of Bt cotton; insect predators increased by 24%.

9.12.2.6 Reduced risk for wildlife

Broad spectrum insecticides are hazardous to wildlife and the various species react quite differently to specific products (USEPA 1998b, c). Reduction in the use of insecticides, many of which are highly toxic to wildlife (USEPA 2001) will reduce the risks to mammals, birds, bees, fish and other organisms. Comparing usage rates prior to commercialization of Bt cotton to usage post-commercialization in the US, there has been a two-thirds decrease for the products most toxic to birds and fish and a one-third decrease in products most toxic to humans (USEPA 2001). The North American Bird Breeding Survey shows a positive correlation between increases in average bird counts, adoption of Bt cotton, and reductions in insecticide usage (USEPA 2001). Whereas direct contact is the most hazardous, the indirect negative impact on habitats can be equally important and is well documented for birds (Ewald and Aebischer 1999). Many birds are dependent on insects for food and their elimination through the use of broad spectrum insecticides deprives birds of their food source.

9.12.2.7 Reduced fuel and raw material consumption, and pollution

Lowering the demand for insecticides, through the use of Bt cotton reduces tractor fuel usage as a result of fewer sprays, which in turn reduces air pollution. Edge et al (2001) note that every liter of diesel fuel produces 1.67 Kg CO_2 (Kern and Johnson 1993). Based on a consumption of 0.373 liters/hectare to apply one spray on one hectare and a reduction of 2.2 sprays for Bt cotton in the US, the release of 638,000 Kg of CO_2 into the environment in 2001 was eliminated.

An analysis has also been made of the tertiary positive environmental impacts resulting from Bt cotton adoption. For the year 2000, the insecticide reduction in key cotton-growing states in the US alone saved 3.46 million pounds (1.57 million kg) of raw materials that would have been needed to manufacture the saved insecticides, conserved over 4 million gallons of fuel oil (15.1 million liters) required to manufacture, distribute and apply saved insecticides and eliminated the need to use and dispose of 416,000 insecticide containers (Leonard and Smith 2001).

In the Hebei Province of China, where adoption of Bt cotton increased dramatically from its introduction in 1997 to 97% in 2001, farmers have noticed a substantial improvement from the chronic air/soil/water pollution levels prior to the introduction of Bt cotton in 1997, caused by the intensive spraying of cotton with insecticides (Biotechnology Global Update 1999).

9.12.3 Social Benefits

Bt cotton significantly increases income and saves time for farmers, thus providing an opportunity to impact the quality of life for farmers and their families. In China, the increased income allows farm families to increase food purchases and food consumption, thus improving nutritional standards (Pray et al 2001). The time savings for women in South Africa gives them more time to devote to high value activities such as caring for children and the sick and allows them to generate additional income by participating in non-farming activities (Ismael et al 2002a). Children in South Africa who no longer have to participate in spraying activities can now devote more time to educational and other worthwhile pursuits (Ismael et al 2002a). These are important examples of how Bt cotton can offer social benefits that extend beyond the farmers' fields and into their home and community. Small resource-poor cotton farmers, 50 % of whom are women in South Africa, spend much of their time carrying water for domestic use and for farm use. It is estimated that annually women and girls in Africa spend 40 billion hours carrying water for domestic and agricultural use including water for spraying pesticides on crops such as cotton (Johns Hopkins University 2002). Water is the staff of life and therefore saving water at a time when global supplies are becoming more limited has profound social implications. Some of the social implications of saving water by significantly reducing the number of insecticide sprays are discussed below, within the broader context of global water usage and availability in developing countries.

9.12.3.1 Social implications of saving water by reducing number of insecticide sprays

Water is a precious resource and every effort must be made to save water to avert the critical global shortages that are foreseen for both industrial and developing countries in the imminent future. The importance of saving water, through every conceivable means, cannot be overstressed because it is the single most important resource in agriculture. Water will become increasingly more limited in the future in both industrial and developing countries as urbanization continues and the demand for water in agriculture continues to increase. A recent IFPRI Report (2002), "Global Water Outlook to 2025: An Impending Crisis" predicts that if the current water crisis continues, water constraints could lead to a reduction of 350 million MT of grain in 2025 which is more than current US annual grain production. As a result, global prices of rice could increase by 40%, wheat by 80%, and maize by 120 % if current demand trends continue.

To put water savings, resulting from reduced insecticide applications into context, it is instructive to consider the minimal water requirements of people as well as the availability of water. A minimum basic requirement of 50 liters per person per day has been proposed to satisfy the basic requirements of drinking, sanitation, bathing and cooking (Glieck 1996). About 55 countries with a combined population of 1 billion failed to meet this minimal standard in 1995. Countries differ significantly in water usage for agriculture; for example, in Africa 88% of the fresh water is used for agriculture compared with 86% in Asia, but only 33% in Europe. In Africa per capita consumption of water is 47 liters per day compared with 85 liters in Asia, 334 liters in the UK, and 578 liters in the US (Johns Hopkins University 2002). Two thirds of the global population obtains its water from public standpipes, wells and other public water sources. In the developing countries much of the water has to be carried over long distances, usually by women and girls.

On a global basis the world consumed 1,799 cubic km of fresh water in 1995, and this is expected to increase to 2,081 cubic km by 2025 (IFPRI 2002). Agriculture is the major consumer of water, using approximately 70% of the fresh water drawn for human use (Engelman and Leroy 1993). Increasing production on irrigated land is critical because even though only 17 % of crop land is irrigated it produces 30 to 40 % of total crop production globally. In the future, agriculture will require significantly more water for irrigation, as irrigated land is expected to increase by 11% by 2025 (IFPRI 2002). Given that agriculture accounts for 70% of all water used for human use, it follows that the greatest opportunity for potential savings is also in agricultural uses. Irrigation is the biggest consumer of water in agriculture and is obviously the key area for achieving savings through increased efficiency. Reducing the considerable volume of water used for applying pesticides, through the use of crops such as Bt cotton, represents a new opportunity to save water which only materialized following the large scale adoption of GM crops in 1996.

The volume of water used per single ground application of insecticide is in the range of 5 to 10 gallons per acre (Williams 2002c). The calculation below uses an average of 7.5 gallons/acre, equivalent to 70 liters/hectare which is conservative, considering estimates from South Africa of 118 liters of water/hectare (Ismael et al 2002a) for knapsack spraying, which usually requires higher water volumes, than the larger tractor drawn sprayers. Some cotton insecticides are applied by air (up to 50% in US), when less water is used (2.5 gals/ acre or 23 liters/hectare). However, on a global scale most cotton insecticide is applied by ground sprayers, with a high percentage applied at higher volumes by powered or hand operated knapsack sprayers by small farmers in developing countries where approximately 70% of cotton is grown.

Small farmers in developing countries have to laboriously carry water for spraying over long distances in harrowing conditions wasting time and effort which could be used much more effectively for more important family duties that are often neglected because of lack of time. The deployment of 4.3 million hectares of Bt cotton globally in 2001 is estimated to have saved 1.7 billion liters of water. This resulted from using 10,627 MT less insecticides (a.i.) used at 0.45 kg a.i./hectare translates to 23.9 million fewer spray-hectares at 70 liters/hectare = 1.7 billion liters of water. For the five million small farmers in developing countries who are currently growing Bt cotton, there has also been an enormous saving of effort for men, women and children who otherwise would have labored unnecessarily to carry water and suffered the additional critical ill-effects from spraying insecticides to control cotton insect pests.

Global potential savings in water from reduced insecticide sprayings from the extended adoption of Bt can be estimated as follows: 81,000,000 kg (a.i.) of cotton insecticide used globally at an average of 0.45 kg/hectare/spray in 2001 translates to 180 million spray-hectares; this is consistent with a global average of approximately 5.5 sprays applied on 33.5 million hectares = 185 million spray-hectares. The amount of water used to apply 81,000,000 kg of a.i. is 180 million spray-hectares x 70 liters = 12.6 billion liters or 3.3 billion US gallons. Potential annual global water savings, from utilizing Bt cotton would reduce insecticide use by half, is estimated at 6.3 billion liters (of which 1.7 billion liters has already been saved) or approximately 1.8 billion US gallons. This significant saving of 6.3 billion liters is considered a conservative estimate given that the water volume used in the calculation is 70 liters/hectare/spray whereas estimates from developing countries are as high as 118 liters/hectare/spray (Ismael et al 2002a). To put this saving into context, 6.3 billion liters would supply a city of 1.5 million people in Africa, with their per capita consumption of 47 liters per day of water, for approximately 3 months.

To put a human face on the social benefits that Bt cotton offers as a result of its reduced requirement for water for insecticides sprays, the following scenario is typical for a woman farmer growing conventional cotton on a resource-poor farm in the Makhathini Flats in South Africa. She spends one day spraying one hectare of conventional cotton; she has to labor hard to carry water from a source that is at least one kilometer from the field; for a single application for one hectare she has to apply 7 knapsack loads/hectare, each load weighing 16 kg (36lbs), for a total of 118 liters (31 gallons) of water per hectare. Using a powered or hand operated knapsack sprayer, she walks 9 km (5 miles)/hectare sprayed, and she is required to repeat the process up to 11 times a season which takes a total of 11 days of arduous work consuming from 770 to 1,300 liters (200 to 340 gallons) of water per hectare. The average cotton area on a farm in the Makhathini Flats is 1.7 hectares of cotton (Ismael et al 2002a) hence the magnitude of the effort required of women, and the corresponding savings, is 70% more than the above estimates for 1 hectare. With

Bt cotton she can reduce the number of sprays from 11 to 4 (Ismael et al 2002a), save 490 to 826 (130 to 218 gallons) liters of water/hectare of cotton, and does not have to walk an extra 60 km or 35 miles. The 7 days per hectare that she saves from using Bt cotton (equivalent to 12 days on the average farm with 1.7 hectares of cotton), can be more usefully devoted to: caring for her children (who often have to help with the intensive spraying for conventional cotton); caring for the sick (AIDS is taking a heavy toll on family members in South Africa); attending to other household duties which currently are often neglected because of the onerous duties of small resource-poor farmers, 50% of whom are women in South Africa. The savings in water and the social benefits associated with Bt cotton are of enormous value to cotton farmers in the developing world who labor hard to survive, and can benefit significantly from the multiple benefits that Bt cotton offers.

In summary, for the average cotton holding of 1.7 hectares of cotton in the Makhathini Flats in South Africa, in a typical season, a woman farmer is relieved of 12 days of arduous spraying, saves over 1,000 liters of water (over 250 US gallons), walks 100 km less, suffers less insecticide poisoning and increases her income significantly by approximately $85/season, through using Bt cotton, rather than conventional cotton.

9.12.4 Economic Benefits

Acknowledging that the economic advantage of Bt cotton is related to the varying level of pest infestation, all countries growing Bt cotton have reported economic gains; these are documented in detail and referenced in the country case studies on pages 85 to 136 in this publication. Based on surveys of commercial Bt cotton and extensive replicated multi-locational trials over several years, the largest economic gains per hectare have accrued to China. The economic gain per hectare for commercial Bt cotton in China has been up to $550 per hectare (Pray et al 2002). Significant and consistent economic gains have been recorded in large scale national field trials in India, ranging from $75 to $200 or more per hectare, with most of the estimates on the higher end of the range. Mexico can have substantial but variable gains. Extensive field trials and surveys in the US have reported average gains per hectare of $50 to $80 and substantially more in some cases. Economic gains from Bt cotton in South Africa are up to $50 per hectare with those in Australia and Argentina ranging from $25 to $50 per hectare.

Global experiences with Bt cotton have clearly demonstrated the economic advantage gained from using this technology. In general the overall economic benefit of Bt cotton results from yield increases, and decreases in insect control costs, which are partially offset by the higher price of Bt cotton seed, including the technology fee where it is applicable. Taking all these factors into account, the highest national economic returns in 2001 accrued to China and the US, which grew 35% and 60% of world Bt cotton respectively. Australia, South Africa, Argentina, Mexico and Indonesia also benefited and are expected to be joined by India and Colombia in 2002. A discussion of the salient issues related to the economic gains from Bt cotton in the respective countries follows.

9.12.4.1 China

An estimated 4 to 5 million smallholder farmers in China have rapidly adopted the technology, increasing from only a few thousand hectares in 1997 to 1.5 million hectares in 2001 (Huang et al 2001, Pray et al 2002, James 2001a). Mean yields have increased 5 to 10% in multiple year comparisons with non-Bt varieties. Bt cotton has resulted in a drastic reduction in formulated chemical insecticide usage - 20,000 tons in 1999, 25,000 in 2000 and 78,000 tons in 2001, lowering the farmers' insecticide costs significantly and reducing the labor required for controlling insects (Huang et al 2002, Pray et al 2002). For China, the overall economic advantage of Bt cotton, compared with non-Bt cotton ranged from $357/hectare in 1999 to $550/hectare in 2000, to $502/hectare in 2001, (Pray et al 2002) with an average of $470/hectare. Taking all 3 years into account, savings on insecticides both in terms of lower cost for the reduced amount of product used and the substantial labor savings from reducing the number of sprays by two-thirds, were the major contributors to decreased production costs and increased profitability. The increase in yield of Bt cotton in China leads to increased revenue, which is partially offset by the slightly higher price of Bt seed.

In 1999, some pessimistic critics voiced concern that an increase in supply of cotton, resulting from higher yields of Bt cotton, would result in lower cotton prices which in turn would result in losses rather than profits for Bt cotton farmers in China. In 2000 an increased supply of cotton was associated with a significant price decrease of approximately 30% in cotton prices between 2000 and 2001 (4.42-4.45 yuan/kg to 3.02-3.04 yuan/kg). Despite this decrease in price, Bt cotton farmers in China still increased their income by approximately $500/hectare compared to non-Bt cotton in 2001 (Pray et al 2002).

It is noteworthy that in all 3 years (1999 to 2001), farmers growing non-Bt cotton in China, with costed labor, were actually making a loss of anywhere from $6/hectare to $183 to $225/hectare, whilst Bt farmers were enjoying substantial profits of up to $500 (Pray et al 2002). To place the economic advantage of Bt cotton in China into context, in 1999 cotton farmers with an average per capita income of $250/annum were generating $350/hectare in net income which translates to an actual additional income of $140 from their average 0.4 hectare planting of Bt cotton; i.e. increasing the income of an average, small, poor farmer by more than 50%. Considering that Chinese cotton producers are small resource-poor farmers, the Chinese experience with Bt cotton supports the thesis in the 2001 UNDP Human

Development Report (UNDP 2001) that technology can contribute to the alleviation of poverty.

At a national level, the economic benefit of Bt cotton in China in 2001, based on adopted area of Bt cotton and net revenue/hectare, was approximately $140 million for 1999, $495 million for 2000, and $750 million for 2001. Of this total of $1.4 billion over three years, about half, $700 million can be attributed to the Bt cotton developed by the Chinese public sector which has invested R&D expenditures of the order of $100 million plus annually on biotechnology for all crops, including cotton (Pray et al 2002). This represents an excellent return on R&D investments for the Chinese government and should provide it with the incentive to implement the government's intent to quadruple its annual R&D budget in crop biotechnology to $450 million by 2005.

In terms of distribution of benefits, the data for China clearly show that in 1999, 83% of total benefits accrued to farmers with a small percentage (15%) to the private sector developer of the technology (Pray et al 2002, 2001). Thus, Bt cotton has been an excellent investment for small, resource-poor Bt cotton farmers in China who captured 83% of the total benefits. It also represents an excellent investment for China as a nation, and for consumers who benefit from more affordable prices for cotton and a safer environment. Bt cotton has significantly impacted the economics of growing cotton in China and the impressive economic gains clearly demonstrate that smallholders adopting this technology can gain significant economic benefits.

9.12.4.2 USA

The economic advantages offered by Bt cotton have led to its rapid adoption in the United States, increasing from 730,000 hectares in its year of introduction (1996) to over 2 million hectares in 2001, equivalent to more than one-third of the total area of US cotton (James 2001b, Edge et al 2001). For 2001, the economic analysis indicates that Bt cotton provided farmers with an increase in net income of $50/hectare (Gianessi et al 2002), equivalent to a national gain of $103 million. With low infestations in 2001, the total cost of insect control was actually $5/hectare higher for Bt cotton when considering the insecticide costs and the cost of the technology fee, but a yield increase of 40 kg/hectare of lint far outweighed the increase in insect control costs, thus resulting in the net economic advantage of $50 per hectare. It is noteworthy that the gain of $50 per hectare in 2001 was realized despite the fact that cotton pest infestations in 2001 were one of the lowest in recent years. The corresponding gain in 1998, when insect infestation was significantly higher, resulted in a higher gain of $84 per hectare (Carpenter and Gianessi 2001).

Yield gains from growing Bt cotton have also been confirmed by replicated, field trials across multiple regions of the US (Carpenter et al 2002, Marra et al 2002, Fernandez-Cornejo and McBride 2000) with an average yield gain of 10% or more (Perlak et al 2001). A number of studies have documented the reductions in the number of sprays needed for controlling lepidopteran pests when using Bt cotton (Carpenter et al 2002, Edge et al 2001). This reduction in sprays translates to additional secondary cost savings as the reduced number of spray trips allows farmers to capture savings on fuel, machinery and labor costs.

The overall economic benefits for Bt cotton farmers in the US in 1998, estimated at $84/hectare, were equivalent to a national benefit of $92 million. Similarly for 1999 the economic advantage of Bt cotton was $52/hectare for a national benefit of $99 million and for 2001 it was $50/hectare for a national benefit of $103 million (Gianessi et al 2002, Carpenter and Gianessi 2001). These estimates are of the same order of magnitude as EPA estimates for Bt cotton that range from $60 to $ 126 million annually. Other estimates of national benefits from Bt cotton in the US include those of Falck-Zepeda et al (1999) who estimated a national gain of $134 million in 1996 and $213 million in 1998. It is noteworthy that farmers were the major beneficiaries capturing 43-58% of the net benefits. In summary, the overall economic benefit for Bt cotton growers in the USA was estimated at $50/hectare to $85 /hectare, after deducting additional costs related to seed and insect protection, which translates to a minimum national gain of $100 million/year at current world prices of cotton.

9.12.4.3 India

While the data is not as comprehensive in India as is the case in countries where the products are already grown on a large hectarage post-commercialization stage, there are some noteworthy trends apparent from the field trial data. For India, two sets of data were used to estimate the overall economic advantage of cotton; the first was a field trial data set for 1998/99 and 2000/01 from the Department of Biotechnology analyzed by Naik (2001) and the second was an ICAR field trial data set for 2001 (ICAR 2002). The data set of Naik (2001) indicates that the overall economic advantage of Bt cotton in 1998/99 was $236 per hectare, equivalent to about 77% gain, compared with conventional cotton. The corresponding figure for the atypical trials of 2000/01, which were planted late, was $76/hectare equivalent to a 25% advantage over conventional cotton; the lower returns in 2001 were entirely due to the lower yield from the later planting, with savings from insecticides being similar ($45 versus $42/hectare) to 1998/99. It is noteworthy that the economic advantage from the yield increases associated with Bt cotton in India is relatively much greater than the cost advantage related to pesticide savings. Thus, in 1998/99 the cost advantage associated with increased yield was $241/hectare compared with $45 from insecticides. This is reflected in the 79% economic advantage for yield with Bt cotton compared with a corresponding 15% for insecticides in 1998/99. Comparing Bt cotton with farmer practice, as opposed to control plots of conventional cotton in field experiments, the overall economic advantage of Bt cotton in 1998/99 was estimated to be in the range of $255 to $278/hectare, which is at the lower end of the corresponding estimates for China, which range from $350 to $500 per hectare.

Naik (2001) also explored the effect of a hypothetical 11% and 17% drop in the international price of cotton in the event that Bt cotton production would increase supply and reduce prices. Under the most pessimistic price scenario of a maximum 17% decrease in cotton prices, the benefits of Bt cotton over farm practices would be reduced in 1998/99 from ($255 to $278/hectare) to ($185 to $230), which still provides handsome returns to Bt cotton farmers.

Based on the ICAR data set from large scale field trials in 2001, the economic advantages for three Bt hybrids were relatively high due to severe pest infestations. The overall economic advantages for the three Bt hybrids ranged from $96/hectare, (a 29% increase compared to conventional cotton) to $210/hectare (86% increase over conventional cotton). The magnitude of the economic advantage is of the same order as the 1998/99 data set analyzed by Naik, 2001 ($236/hectare). The data for the 2001 ICAR trials are also consistent with the 1998/99 Department of Biotechnology data set in that the major contribution to economic advantage is due to yield advantage, as opposed to insecticide product and labor reduction costs. However, the benefits in terms of farming practice can be expected to reflect a higher contribution from insecticide savings, because of the high number of prophylactic sprays applied by farmers.

In summary, the results of field experiments in India indicate that, with typical high insect pest infestations, the overall economic benefits from commercial Bt cotton are likely to be high, ranging from $75 to $200/hectare or more. The first commercial plantings of approximately 45,000 hectares were planted in India in 2002.

9.12.4.4 Other countries growing Bt cotton

In the state of Coahuila and Durango in Mexico, Bt cotton generated an estimated $2.7 million in economic benefits annually in 1997 and 1998, of which the vast majority (85%) flowed to the farmers (Traxler et al 2001). In Mexico, when pest infestations were low in 1997, the overall economic advantage was $44/hectare compared with $626/hectare in 1998 when pest infestation was higher. The higher yield of Bt cotton in 1998 was the major contributor ($543/hectare) to the overall economic advantage of $626/hectare; yield of Bt cotton in 1998 was 20% higher, as opposed to 3% in 1997. In 1998 cost savings for insecticide were $139/hectare which were offset by higher Bt cotton seed cost of $56/hectare, resulting in an overall economic advantage for Bt cotton of $626 per hectare.

In South Africa, Ismael et al (2002a,b) have completed three years of study on the impact of Bt cotton on smallholder farmers in the

Makhathini Flats. Yield advantages for Bt cotton, coupled with insecticide and labor savings which are partly offset by higher seed costs, result in an overall economic advantage of the order of $50/hectare for small Bt cotton farmers in the Makhathini Flats (ISAAA 2002d). Other estimates that exclude labor savings (Kirsten et al 2002) indicate an economic advantage of $35/hectare for small farmers, and ranging from $19 to $34/hectare for large farmers under rainfed and irrigated conditions respectively. Bt cotton growers in South Africa have benefited from higher yields than non-adopters and significantly lower chemical application costs. These benefits outweighed the increased seed and harvest costs of Bt cotton, creating higher gross margins and a net economic advantage for Bt cotton growers of about $25-$50 per hectare. The adoption rate for Bt cotton by small farmers in the Makhathini Flats has been very rapid, increasing from 4% of the growers in 1998 to 92 % in 2001. The majority of the adopters had farm sizes of less than three hectares, farming on average 1.7 hectares of cotton, once again clearly demonstrating that smallholder farmers can realize the economic benefits of Bt cotton.

In Argentina gross margins have been modest and variable, ranging from $5 to $36/ hectare (Qaim and de Janvry 2002) to $65/hectare (Elena 2001). Given the low-cost system of cotton production in Argentina, Qaim and de Janvry concluded that the relatively high price of Bt cotton seed ($103/hectare) is an impediment to higher adoption rates which have stagnated at about 5% of the national cotton hectarage. Lower prices for Bt cotton seed could stimulate adoption rates and improve margins for farmers as well as optimizing returns for the developers of the technology.

In Australia, overall economic benefits of Bt cotton have been low to modest and ranged from $6/hectare in 1998/99 to $50/hectare in 1999/00 (Fitt 2002/In Press). The principal 'economic gain' of Bt cotton is related to the fact that farmers are not required to operate an intensive spray control program throughout the season, with its associated negative effects on the implementation of the IPM program, which is assigned high priority. Despite only modest returns from Bt cotton, farmers have purchased the full quota of Bt cotton seed available each year because they are convinced of its environmental benefits and that it provides a foundation for a sustainable IPM strategy. In Indonesia, preliminary evaluations of Bt cotton indicate that farmer income increases due to higher yields (30% average), reduced pesticide usage and better productivity (ISAAA 2002e).

The positive experience of eight countries which are already benefiting from Bt cotton would suggest that farmers in other countries, suffering losses from the major lepidopteran pests of cotton could also realize significant economic benefits from growing Bt cotton. In summary, the seven countries that have adopted Bt cotton have realized significant economic gain, with India probably poised to realize similar benefits from 2002 onwards. The USA and China have been the largest

Table 79. Estimates of Global Benefits from Bt Cotton 1998 to 2001 ($ Millions)

	China	USA	Others	Total
1998	N/A	92	<1	**93**
1999	140	99	2	**241**
2000	495	N/A	>3	**498**
2001	750	103	5	**858**
Total	**1,385**	**294**	**11**	**1,690**

Source: Compiled by Clive James 2002, from estimates for China by Pray et al., 2002 and for USA by Gianessi et al., 2002 and Carpenter and Gianessi, 2001.

absolute beneficiaries to date because they grew 60% and 35% of global Bt cotton in 2001 respectively. The national benefits associated with Bt cotton in China were by far the largest, increasing from $140 million in 1999, to $495 million in 2000, to $750 million in 2001, for a three year total of $1.385 billion (Table 79). National benefits associated with Bt cotton in the USA were $92 million in 1998, $99 million in 1999, (2000 estimate not available) and $103 million in 2001, when infestation was very low, for a three year total of $294 million. Benefits for the other 5 countries that have adopted Bt cotton during the period 1998 to 2001 are estimated at $11 million – the total area planted in the six countries to Bt cotton is modest but growing. Thus, the global benefits for Bt cotton during the period 1998 to 2001 is estimated at approximately $1.7 billion (Table 79), which is a substantial benefit. It is particularly impressive given the fact that over three quarters of the benefits in 2001 have been realized by up to 5 million small resource-poor farmers in developing countries, mainly in China, which elected to make its own investments in the technology and is now reaping the benefits.

9.12.4.5 Distribution of economic surplus to Bt cotton stakeholders

One of the "corporate" concerns often voiced by the critics of biotechnology relates to their perception that, the developers of transgenic crops (usually, but not exclusively private sector transnational corporations) are the major or sole beneficiaries from transgenic crops. Analysis of the distribution of economic surplus from Bt cotton in the US, Mexico and China is summarized in Table 80. The data in Table 80 show the distribution of benefits to the various stakeholders associated with Bt cotton – farmers, technology developers, seed suppliers, consumers, and global society at large as represented by the category "Rest of the World" in Table 80.

Table 80. Distribution of Share of Economic Surplus from Transgenic Crops (Expressed as %), for Different Stakeholders

	Bt[1] Cotton 1996 USA	Bt[2] Cotton 1997 USA	Bt[3] Cotton 1998 USA	Bt[4] Cotton 1997 Mexico	Bt[4] Cotton 1998 Mexico	Bt[5] Cotton Public 1999 China	Bt[5] Cotton Private 1999 China
Farmers	59	42	46	61	90	83	83
Tech Developer[6]	21	35	34	31	8	-	12
Seed Supplier[6]	5	9	9	8	2	17	5
Consumers	9	7	7	-	-	-	-
Net Rest of the World	6	7	4	-	-	-	-
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Sources: Compiled by Clive James, 2001a from the following sources:
[1]Falck-Zepeda et al., 2000b; [2]Falck-Zepeda et al., 2000a; [3]Falck-Zepeda et al., 1999; [4]Traxler et al., 2001; [5]Pray et al., 2001; [6]Gross Revenue R&D, marketing and other costs not deducted.

Seven studies featuring Bt cotton in the US in 1996, 1997 and 1998, Mexico in 1997 and 1998, and China in 1999 are summarized in Table 80. The first study (Falck-Zepeda *et al* 2000b) indicates that of the total economic surplus generated through the use of Bt cotton in the USA in 1996, the relative economic advantages to the various stakeholders were as follows: the largest share of the economic surplus went to US farmers (59%), the developer of the technology (21%), the seed supplier (5%), US consumers (9%), with the balance of 6% as economic surplus to the rest of the world. Note also that the share of the surplus to the technology developer and the seed supplier is gross revenue, with R & D marketing and other costs not deducted, whereas the share to the farmers and consumers are net gains. This under-estimates the relative gains to farmers and consumers versus the technology developer and seed supplier.

The second study for the US in 1997 (Falck-Zepeda et al 2000a) also shows that farmers were the major beneficiaries 42% versus 35% for the technology developers. Similarly, the 1998 survey for the US (Falck-Zepeda et al 1999) shows that farmers captured 46% and technology developers 34%. The two studies conducted in Mexico in 1997 and 1998 (Traxler et al 2001) also show that farmers were the major beneficiaries capturing 61% and 90% of the surplus in 1997 and 1998 compared with 31% and 8 % respectively for the technology developers. In the 1999 Chinese study, Pray et al (2001) provides information on economic advantages to small farmers in

China acquiring Bt cotton from two different developers of technology: one source is the public sector (CAAS) and the other the private sector (Monsanto/Delta Pine Land). In the case of the Bt cotton developed by both public sector and private sector, the farmers' share of surplus (Table 80) was 83% (Pray et al 2001).

Taking into account all seven case studies on the distribution of benefits to Bt cotton stakeholders in three countries, there is no evidence (Table 80) to support the perception of the critics of biotechnology that the transnational corporate developers of transgenic crops are the major or sole beneficiaries from transgenic crops. On the contrary, the summary of relative benefits expressed as percentage share of economic surpluses in Table 80 confirms that not only were farmers significant beneficiaries in all studies but were consistently the major beneficiaries, receiving 49 to 90% of the surplus, in all seven studies with an average share of two thirds (66%) of the economic surplus. The studies to-date indicate that the relative economic advantages are not dissimilar to farmer/input supplier benefit ratios that apply to conventional agricultural products and are not heavily in favor of the developers of transgenic crops as some critics have suggested.

9.13 Global Potential of Bt Cotton: Opportunities and Challenges

A wealth of past experience and knowledge is usually invaluable in projecting future trends and developments. Accordingly, in attempting to assess the global potential for Bt cotton, the information on lepidopteran pests of cotton, their control, as well as the assessment of the impact of Bt cotton reviewed in this chapter, provides a knowledge base on which assumptions and future projections of potential benefits can be based. It is evident that the major lepidopteran pests, particularly the bollworm complex, are a major constraint to increased productivity, and are of economic importance in most cotton-growing countries. Ninety percent of the cotton area in the 50 key countries have medium to high levels of lepidopteran pests (Table 81). This conclusion is not only supported by the voluminous published and unpublished data on the incidence and severity of lepidopteran cotton pest infestations, but corroborated by the need to apply over 80,000 MT of cotton insecticide (a.i.) annually in the 50 key countries that grow cotton throughout the world. The cost of cotton insecticides at the farm level in 2001 was $1.7 billion, with more insecticide consumed by cotton than any other single crop – 20% of the insecticide applied globally to all crops in 2001 was applied to cotton. Damage to cotton from insect pests will vary and is dependent on the level of pest infestation, weather, and variety. Thus, the number of sprays applied to control lepidopteran pests in different countries varies from an average of about 2 sprays per season to 12, and the maximum can reach 30 sprays in countries like China where infestation levels can be extremely high.

The information from the eight Bt cotton-growing countries, reviewed in this chapter,

Table 81. Estimated Potential Savings of Cotton Insecticide (Metric Tons (MT) of Active Ingredient (a.i.)) in the Top 50 Cotton-Growing Countries and Lepidopteran Pest Infestation Levels

Insecticide (a.i.) Savings MT	Asia MT	Americas MT	Africa MT	Europe MT	Total MT (%)[1]
CATEGORY 1 > 5,000	China H India H				**23,536** (68%)
CATEGORY 2 1,000 to 5,000	Pakistan H	USA M			**4,932** (14%)
CATEGORY 3 500 to < 1,000	Australia H	Brazil M			**1,296** (4%)
CATEGORY 4 400 to < 500	Uzbekistan H				**472** (1%)
CATEGORY 5 300 to < 400			Burkina Faso MH		**324** (1%)
CATEGORY 6 200 to < 300	Turkey L		Mali MH Benin MH Egypt H		**1,136** (4%)
CATEGORY 7 100 to < 200	Turkmenistan L Myanmar H Iran L	Paraguay H	Cote d'Ivoire MH Nigeria MH Zimbabwe MH Chad MH Mozambique MH Cameroon MH	Spain H Greece L	**1,842** (5%)

continued ...

Table 81 Cont'd. Estimated Potential Savings of Cotton Insecticide (Metric Tons (MT) of Active Ingredient (a.i.)) in the Top 50 Cotton-Growing Countries and Lepidopteran Pest Infestation Levels

Insecticide (a.i.) Savings MT	Asia MT	Americas MT	Africa MT	Europe MT	Total MT (%)[1]
CATEGORY 8 **50 to < 100**	Tajikistan L Kazakhstan L Syria L	Colombia H Argentina H Peru H	Tanzania MH Zambia MH Sudan MH Togo MH		**597** (2%)
CATEGORY 9 **< 50**	Thailand H Indonesia H Bangladesh H Vietnam H Philippines H	Mexico H Bolivia H Ecuador H	Uganda MH South Africa MH Ethiopia MH Madagascar MH Ghana MH Senegal MH Kenya MH Guinea MH		**483** (1%)
TOTALS **# of Countries** (%)[1]	**27,790** **17** (80%)	**3,799** **9** (11%)	**2,585** **22** (8%)	**369** **2** (1%)	**34,543** **50** (100%)

Source: Clive James, 2002. Savings of insecticide per country (MT) based on 0.45 kg a.i. per spray x # of saved sprays due to Bt cotton x 50% of cotton hectares.
L represents Low infestations of Lepidopteran pests up to 30% of national cotton area affected.
M represents Medium infestations of Lepidopteran pests between 31 and 70% of national cotton area affected.
MH = Medium to High.
H represents High infestations of Lepidopteran pests over 70% of national cotton area affected.

[1] Expressed as percentage of 34,543 Metric Tons.

confirms that the technology provides effective control of the bollworm complex, resulting in increased yields, a reduction of at least half in the number of insecticide sprays, leading to increased profitability because of lower production costs and higher yields. Information on severity of pest infestation indicates that approximately 70% of the cotton area in countries such as India and China (Table 81) that grow large areas of cotton, would benefit from Bt cotton. This conclusion is supported by the fact that adoption in the US, which has a medium level of infestation, compared with the high infestation in China and India, has already reached 35% to 40%, and will likely reach 50% as improved technology, such as Bollgard® II and similar products are introduced in the imminent future. Countries such as India and China (already >30% adoption), which together grow 40% of the global area of cotton are expected to exceed 50% adoption of Bt cotton. India is expected to follow the steep Bt cotton adoption curves witnessed in China. Other major cotton-growing countries, like Australia which currently limits adoption of INGARD® to 30%, have eliminated this limitation for Bollgard® II, which is expected to reach 70% adoption in the future. Given high levels of infestation with lepidopteran pests globally and the application of a relatively high number of insecticide sprays, the potential for Bt cotton adoption rates to reach or exceed 50% is also likely in other key cotton countries, which currently do not grow Bt cotton. These include Pakistan (3.1 million hectares) in Asia, Brazil (750,000 hectares) in Latin America, and Mali (516,000 hectares) and Tanzania (392,000 hectares) in west and east Africa respectively.

In the absence of a comprehensive set of field trial data to measure the performance of Bt cotton versus conventional cotton in the 50 key cotton-growing countries globally, estimating the potential savings of insecticides in each country, based on current insecticide usage, can serve as one indication of the relative benefits to individual countries and the potential for Bt cotton globally. Based on data presented in this review, it is evident that Bt cotton can reduce by at least 50% the number of insecticide sprays currently used on conventional cotton, and that a projected maximum of 50% potential adoption rate is realistic given that heavy infestations in India and China, which grow 40% of the world's cotton, will probably lead to adoption rates exceeding 50%. Thus, potential savings in cotton insecticides for a specific country, as a result of projected adoption of Bt cotton, can be estimated from:

- The area of cotton (hectares) in the country x 0.5 which assumes a maximum 50% adoption
- The average number of insecticide sprays x 0.5, which assumes a reduction of half in the number of sprays applied to Bt cotton versus conventional cotton
- An average insecticide application rate of 0.45 kg a.i./spray/hectare for cotton insecticide (Benedict and Altman 2001).

The calculation is essentially the same as that used by Benedict and Altman (2001) to estimate the insecticide savings due to Bt cotton in the US in 1998: 0.45 kg/hectare x reduction in number of sprays due to Bt x hectarage of Bt cotton. Phipps and Park (2002) also used the same formula to calculate the global savings in insecticides due to Bt cotton in 2000, and applied the same principle to estimate insecticide and herbicide savings due to GM maize, GM soybean and GM canola. Applying 0.45 kg a.i./hectare/spray x the global average of approximately 5.5 sprays x global area of cotton (33.4 million hectares in 2001) projects a global usage of 82,665 MT in 2001, which is consistent with the actual usage of 81,200 MT in 2001 (Wood Mackenzie 2002).

Applying the above formula to 50 key cotton-growing countries, using information on cotton hectarage generates estimates of annual insecticide savings (MT a.i.) per country (Table 81). Country savings in insecticides have been allocated to 9 categories, listed in descending order of savings. Given that the data in Table 81 are estimates of the relative share of benefits to individual countries within a global context, caution should be exercised in interpreting the data, because a low global share does not imply that the country in question cannot benefit from Bt cotton. On the contrary, of the 16 countries in the lowest category (Category 9) in Table 81, three countries, South Africa, Mexico and Indonesia, with high lepidopteran infestations, are already benefiting from Bt cotton, with small farmers in the Makhathini Flats of South Africa enjoying significant economic, health and social benefits.

Currently nine countries benefit from growing Bt cotton. For these nine countries the estimates in Table 81 include both current and projected savings of insecticides. Of the 50 countries, the majority, 39 (78%), are developing countries, 3 are West Asian countries (Turkey, Syria and Iran), 4 are Central Asian Republics (Uzbekistan, Turkmenistan, Tajikstan and Kazakhistan), and 4 are industrial countries (USA, Australia, Spain and Greece). Of the 39 developing countries, 22 are from Africa, 9 from Asia, and 8 from Latin America. Thus, in terms of numbers of countries the major potential beneficiaries from Bt cotton are clearly developing countries, with Africa featuring prominently. By and large, cotton is grown by small farmers in developing countries, and hence the extended adoption of Bt cotton to developing countries would be of high value because of the contribution that Bt cotton can make environmentally, healthwise, economically and socially, including the alleviation of poverty and a better quality of life.

Within a global context the relative magnitude of the potential benefits, measured in terms of insecticide savings, most of the global share of benefits would be in Asia (27,790 MT or 80%), followed by the Americas (11%), Africa (8%) and Europe (1%). The fact that Asia captures most of the global benefits does not imply that Bt cotton has no potential for countries in the Americas, Africa and Europe. Countries such as Brazil and Paraguay in Latin

America, Burkina Faso and Tanzania in Africa, and Spain in Europe can benefit equally from the technology.

The country savings in insecticides, allocated to 9 categories in Table 81 and listed in descending order of savings, are an indication of the relative potential for Bt cotton in the respective countries. Thus, category 1 with potential savings of > 5,000 MT (a.i.) annually captures 68% of the global potential of Bt cotton and includes China and India which have by far the highest potential for Bt cotton. This is not surprising because China and India have large areas of cotton (#1 and #3 in the world), and have high levels of infestation with lepidopteran pests which require some of the most intensive insecticide spray programs worldwide. China has already adopted Bt cotton on approximately one-third of its 4.8 million hectares of cotton, with expectations that adoption will exceed 50% in the near term. India is probably poised to emulate the high adoption rates of China and the ultimate rate of adoption may exceed that of China due to the high and more uniform level of infestation in different regions of India.

The second category (savings of 1,000 to 5,000 MT) captures 14% of the global potential for Bt cotton and includes the USA, with a large cotton area with a relatively lower level of infestation (medium) and less intensive spray programs than China and India. Pakistan which is also in the second category has not yet adopted Bt cotton, but the potential is high given its relatively large area (3.1 million hectares compared with 5.6 million hectares in the US) and infestation levels that are higher and insecticide control programs that are more intensive than the US.

There are two countries in the third category (savings of 500 to <1,000 MT), Australia and Brazil. Australia, the only industrial country in Asia-Pacific (Oceania) that has high potential for Bt cotton, is already commercializing the product, and will introduce Bollgard® II in 2002; this will enhance the benefits of the new technology and lead to adoption rates well in excess of 50%, probably around 70%. Brazil, with 750,000 hectares of cotton and medium levels of infestation, is the notable country in the Americas with high potential for Bt cotton but conspicuous by its absence amongst the list of countries which have adopted the technology.

In Category 4 (savings of 400 to <500 MT), Uzbekistan features as one of the countries. Based on limited information, lepidopteran populations are thought to be low in Uzbekistan and the other three Central Asian States and thus the potential for Bt cotton is more uncertain. More information is required from the four central Asian countries to confirm the infestation levels and the relative importance of the different pests, as well as the efficacy of extensive biological control programs and the scope and extent of insecticide control programs.

Category 5 (savings of 300 to <400 MT) includes only one country, Burkina Faso in West Africa, which has high potential and where a significant area of cotton (350,000 hectares) is subject to heavy infestations of lepidopteran insect pests that require 7 to 8 insecticide sprays per season.

Category 6 (savings of 200 to <300 MT) includes one west Asian country (Turkey), two from West Africa (Mali and Benin), and Egypt from North Africa. Egypt represents a high potential opportunity and is unique in that it grows the extra long staple *G. barbadense*, as opposed to *G. hirsutum*. Egypt has already tested Bt cotton in contained facilities and there is a probability that it may field-test Bt cotton in the near term. Bt cotton field trials have been conducted in Turkey where the lepidopteran pests are of medium to low severity and there may be some potential. Both Mali and Benin have high levels of lepidopteran pests, have shown interest in the technology and have high potential.

Category 7 (savings of 100 to <200 MT) has 12 countries including three from Asia (Turkmenistan, Myanmar and Iran), six from Africa (Nigeria, Zimbabwe, Chad, Cote d'Ivoire, Mozambique and Cameroon), one from Latin America (Paraguay), and two from Europe (Spain and Greece). All the African, and Latin American countries and Myanmar have medium to high infestation and high potential whereas potential is lower and more uncertain in Turkmenistan and Iran. Spain has high potential and already grows Bt corn and thus has the regulatory system in place to facilitate the commercialization of Bt cotton; potential is lower in Greece because of lower infestation although hectarage is significant (381,000 hectares). Field trials have been conducted in Zimbabwe where there is good potential and where small farmers recently made a plea for Bt cotton because under current conditions they cannot afford the insecticides, which are a prerequisite for profitable production of conventional cotton. The President of Nigeria has recently allocated significant funding for biotechnology and Bt cotton is an attractive proposition for Nigeria (180,000 hectares of cotton) as it is for West African countries such as Chad (312,000 hectares), Cote d'Ivoire (285,000 hectares) and Cameroon (202,000 hectares) where cotton is a very important cash and export crop.

Category 8 (savings of 50 to <100 MT) includes 10 countries, three from Asia (Tajikistan, Kazakhstan and Syria), all with low infestations, four from East and West Africa (Tanzania, Togo, Zambia, and Sudan), all with medium to high lepidopteran pest levels and three from Latin America (Colombia, Argentina and Peru), all with high pest levels and high potential. Five percent of the cotton area in Argentina is already Bt cotton with the first introductory planting of Bt cotton in Colombia in 2002. Tanzania has declared an interest in the technology. With the exception of the Central Asian States, all other countries in Category 8 represent potential opportunities for Bt cotton.

There are 16 countries in Category 9 (savings of <50 MT), the last category, including five from Asia (Thailand, Indonesia, Bangladesh, Vietnam, and the Philippines), eight from Africa (Uganda, South Africa, Ethiopia, Madagascar, Ghana, Senegal, Kenya and Guinea), and three from Latin America (Mexico, Bolivia, and Ecuador). All of these countries have medium to high pest infestations and are potential opportunities for Bt cotton even though some have a small hectarage of cotton. Mexico, South Africa and Indonesia are already growing Bt cotton, and it has been field-trialed in Thailand. Several countries, growing 30,000 hectares of cotton, or less, in both Asia and Africa, including Vietnam, Philippines and Kenya have expressed interest in the technology and indicated their desire to field-trial Bt cotton. From the country's viewpoint, high levels of lepidopteran pests and intensive insecticide applications merit the adoption of Bt cotton despite the relatively small cotton hectarage.

The data in Table 81 confirm that Asia is characterized by a few large cotton-growing countries dominating the region with high levels of infestation. In terms of global share and benefits, India (8.7 million hectares), China (4.8 million hectares) and Pakistan (3.1 million hectares) and Australia (400,00 hectares), collectively grow 50% of the world's cotton area and stand to gain the most from Bt cotton. This translates to a substantial potential benefit from Bt cotton for these four cotton-growing countries in Asia. Pakistan represents the only country with high potential that has not yet adopted the technology. The other cotton-growing countries in South East Asia and South Asia represent relatively smaller areas but nevertheless important potential opportunities from the perspective of national programs.

Whereas there are nine developing countries that have a potential to benefit in Asia, there are 22 developing countries in Africa, all with small to medium hectarage of cotton ranging from 30,000 to 500,000 hectares. There are opportunities for countries from all regions of Africa to adopt Bt cotton, where the levels of lepidopteran pests are medium to high, with heavy insecticide applications. In West and Central Africa there are 12 countries (Burkina Faso, Mali, Benin, Nigeria, Chad, Cote d'Ivoire, Cameroon, Togo, Zambia, Ghana, Senegal, and Guinea), in Eastern and Southern Africa another 9 countries (Zimbabwe, Mozambique, Tanzania, Sudan, Uganda, Ethiopia, Kenya, Madagascar and South Africa), and Egypt in North Africa. Although cotton production in many of these countries is modest to small, it is often the only cash crop and represents an important, or the most important export commodity. The fact that the global share is relatively small should not lead to an underestimation of the important potential benefits that can accrue to African countries. South Africa, with a modest hectarage of cotton, is already deriving significant benefits, which are of particular importance to small holders. Thus, small cotton farmers in Africa could gain significant benefits from cotton which would not only impact on production and economics but also on the health and social aspects. The latter is of particular relevance to women who farm approximately 50% of the cotton in the countries of Africa. Of the 22 African countries that can potentially benefit from Bt cotton, only one, South Africa, has adopted Bt cotton, but there are several countries that are expressing increased interest including Egypt, Burkina Faso, Mali, Nigeria, Zimbabwe, Tanzania, Uganda, Zambia and Kenya.

Compared with 17 potential countries that could benefit from Bt cotton in Asia and 22 in Africa, there are only 9 potential beneficiary countries in the Americas. The nine countries in the Americas have medium or high levels of lepidopteran pests and stand to gain about 10% of the global benefits from Bt cotton with the US being the main beneficiary. Of the 9 countries that are potential beneficiaries, four have already adopted Bt cotton, USA, Argentina, Mexico, and Colombia. Argentina (152,000 hectares) and Mexico (80,000 hectares) have modest hectarages of Bt cotton with both large and small farmers benefiting from the technology. The largest unexplored potential for Bt cotton in the Americas is Brazil, which grows approximately 750,000 hectares of cotton, mainly in an intensive production system in the southern region of the country, where pest infestation is medium requiring 8 or more insecticide sprays per season. Paraguay grows a modest area of cotton of 150,000 hectares where pest infestation is high, requiring about 8 sprays per season. Peru grows 102,000 hectares and applies about 4 sprays per season. Bolivia (15,000 hectares) and Ecuador (5,000 hectares) grow small areas of cotton, but with a potential for significant benefits to small holders.

In Europe, only two countries are potential beneficiaries of Bt cotton – Spain with 88,000 hectares and Greece with 381,000 hectares. Both countries suffer from lepidopteran pests but the damage level is significantly higher in Spain, which offers the highest potential gains. Field experiments in Spain indicate that up to 5 sprays could be saved with the use of Bt cotton (Edge et al 2001). Greece applies an average of four or more sprays per season.

The data in Table 81 is a first cut at estimating the potential for Bt cotton in the respective countries. It does not take into account the additional and potentially substantial benefits associated with increases in yield from Bt cotton and labor savings from reducing insecticide sprays by 50%. National governments interested in pursuing the potential benefits of Bt cotton for their respective countries can implement comparative field trials of Bt and conventional cotton to generate national domestic data to reliably assess these benefits at the field and national level. These field trials would require approval under the appropriate national regulatory framework, which, if not already in place would have to be established using Bt cotton as the technology to facilitate its promulgation. In practice it is evident that for a country to be a beneficiary, other criteria need to be met, including the necessary infrastructure to manage and commercialize the technology, seed processing and distribution, implementation of an Insect Resistance Management strategy, and adherence to intellectual property rights. These factors, as well as the hectarage of cotton will impact on the decision of a country to commercialize Bt cotton. For smaller countries in the same region, there is an opportunity to cooperate in commercializing the technology, because regional cooperation can often provide the critical mass that is not possible at a national level. Cooperation brings added advantages of the benefits that result from the collective comparative advantages of partners, sharing of costs, and harmonization of regulatory procedures.

From a global viewpoint, an international initiative to extend the adoption of Bt cotton must also anticipate and consider the implications of a significant expansion in the global area of Bt cotton. These considerations at the international level are similar to those at the national level and include necessary global strategies for responsibly managing and optimizing the durability of resistance, and the spatial and temporal deployment of different varieties carrying different sources of resistance. It is a prerequisite to establish an international mechanism to formulate, coordinate and oversee a global strategy for deploying Bt cotton responsibly and effectively without the onerous bureaucracy that usually paralyses such legitimate endeavors. Whereas globalization presents such new challenges in terms of international collaboration, it also presents new opportunities for developing countries to access new technologies that otherwise would be unavailable to them. The global deployment of Bt cotton presents new opportunities for public and private organizations to collaborate in a win-win mode to bring environmental, economic, health and social benefits to small and large farmers and society at large in developing countries. Failure to extend the adoption of Bt cotton to more developing countries that wish to benefit from it will deny their farmers superior technology and further disadvantage them relative to their counterparts in industrial and developing countries who are adopting Bt cotton. From a biosafety viewpoint the natural barriers to outcrossing in the cotton crop makes it a model candidate for adoption in developing countries. Similarly, its principal use as a fiber crop, rather than a food/feed-crop, facilitates its acceptance by the public at large, particularly in view of the multiple and significant environmental, economic and social benefits it delivers. Furthermore, there is now six years of experience in six developing countries, on all three continents of the South, which have already commercialized the technology and can share their experience.

In summary, Bt cotton is a proven safe and effective technology that can deliver substantial and significant benefits to society at large – this makes Bt cotton a unique candidate for extended deployment in developing countries. With the adoption of any technology, there is always a risk that unintended or unforeseen effects could present new challenges. However, with the significant and substantial proven benefits that Bt cotton offers developing countries, the greatest risk is not to explore the technology, and thus be certain to suffer the consequences of inferior technology that will disadvantage farmers in developing countries who have to compete in international markets. The opportunities for capturing the potential benefits that Bt cotton offers the developing countries are summarized in the highlights that close this chapter on the global potential benefits of Bt cotton – the challenges and the opportunities.

Highlights

- **Asia captures 80% of the global share of the potential benefits of Bt cotton. The three countries with the large cotton areas, China, India and Pakistan, as well as Australia with a smaller cotton area, capture most of the benefits (95%) within Asia. Pakistan is the only country amongst the four where there is major untapped potential for Bt cotton. There are five additional potential beneficiary countries in South and South East Asia where Indonesia is already benefiting from Bt cotton.**

- **The Americas capture 11% of the global potential benefits with the US by far the major beneficiary (72%), with a significant unutilized potential in Brazil. The remaining 7 national programs in the Americas all have high infestations and stand to gain from Bt cotton. Mexico and Argentina have already adopted Bt cotton and Colombia had an introductory planting of Bt cotton for the first time in 2002, leaving 4 countries growing small to modest areas of cotton in Latin America as potential beneficiaries.**

- **Unlike Asia and the Americas, there are no dominant cotton-growing countries in Africa, capturing a significant global share of benefits from Bt cotton. However, there are 22 national programs planting from 30,000 to 500,000 hectares of cotton, which could stand to gain from Bt cotton and collectively capture 8% of global share. Infestation levels are medium to high in all countries with South Africa already benefiting from Bt cotton. Egypt is unique in that it grows the extra long staple *G. barbadense* cotton and suffers from high infestation and thus the benefits could be significant. There are 11 countries in West Africa and 9 in East and Central Africa that have small to modest areas of cotton and could benefit from Bt cotton.**

- **Europe is estimated to capture 1% global share of the benefits, with Spain projected to gain more than Greece because of the significantly higher level of infestation, albeit on a smaller area of cotton.**

- **The six countries in the top 3 categories, China and India (Category 1), USA and Pakistan (Category 2), and Australia and Brazil (Category 3) capture over 85% of the potential global benefits. Four of the six countries, China, India, Australia and USA, are already benefiting from Bt** cotton, whilst Pakistan, with high infestation and Brazil with medium infestation represent significant untapped gains. Note that the estimated savings of 29,764 MT of insecticide for the top six countries is conservative since it assumes a 50% adoption, whereas in practice it is more likely to be about 70%.

- Based on the data in Table 81, the potential savings in insecticide are approximately 34,543 MT a.i. annually, equivalent to 40% of the 81,200 MT of insecticide used globally on cotton in 2001. If the collective projected savings (1,400 MT) in the 8 countries with low infestations (4 Central Asian States, Turkey, Syria, Iran and Greece) are discounted, then the revised projected saving on insecticide is approximately 33,000 MT, equivalent to 37% of the 81,200 MT of cotton insecticides used globally in 2001. Based on a global value of $1.7 billion at the farmer level for 81,200 MT of global cotton insecticides in 2001, the annual value of the 33,000 MT saving is $690 million, of which by far the largest share will accrue to Asia; more specifically the significant beneficiaries are the six large cotton-growing countries with medium to high levels of infestation, China, India, USA, Pakistan, Australia and Brazil. Note that the estimated potential annual saving of $ 690 million is only for insecticide product and does not include the additional substantial benefits from increased yield and the significant labor savings that would result from decreasing the number of insecticide sprays by 50% or more through the adoption of Bt cotton. Based on the experience of the countries that have commercialized Bt cotton to-date, the total potential global savings from adopting Bt cotton in all countries with medium to high infestations of lepidopteran pests would be a significant multiple of the $690 million potential annual savings which is only attributable to the value of the saved insecticide product.

- The six countries with large potential benefits from Bt cotton have either already adopted Bt cotton, (China, India, USA and Australia) or are exploring its development (Pakistan and Brazil). The challenge is to provide an opportunity for the countries with smaller to modest areas of cotton in the developing world where several factors preclude access to Bt cotton. These include lack of a regulatory framework to field test the technology, or the transaction cost may be too high for commercializing a relatively small area of cotton. However, it is important that these smaller cotton-growing countries with resource-poor cotton farmers are offered the option of commercial access so that they are not disadvantaged by being denied the significant benefits that accrue to adopters of Bt cotton. There are 30 such developing countries in Africa (21), Asia (5) and Latin America (4) that have medium to high infestations of lepidopteran pests and could benefit significantly from Bt cotton. The China and South Africa experiences with Bt cotton have clearly demonstrated that Bt cotton can make a significant contribution environmentally, economically and socially, and in particular to the alleviation of poverty and improved health of small resource-poor farmers.

- Creative initiatives must be developed by the international development community that will allow potential beneficiary small countries to have the option to participate in a coordinated initiative, designed to deliver responsible and cost effective solutions to the common constraints facing resource-poor cotton farmers in small developing countries. Failure to do this will condemn and further disadvantage small resource-poor cotton farmers in small developing countries, compared with their counterparts in both the industrial and developing countries who are already benefiting from Bt technology. Unlike biotechnology transfer programs featuring orphan food staple crops such as sweet potato or cassava which are non-commercial and not traded or exported, cotton is exported and traded internationally and developing countries have to compete in the international market place. Hence they must have access to equally competitive technology if they are not to suffer a disadvantage compared with adopters of superior technologies. Bt cotton offers a unique opportunity for small resource-poor cotton farmers in developing countries to derive significant agronomic, environmental, economic, health and social benefits. The perceptions of the critics of biotechnology should not dissuade interested smaller developing countries from continuing to pursue their intent to field test Bt cotton in their own countries and reserve their sovereign right to make decisions re the adoption of the technology based on the country's own assessment of the technology. In a recent presentation, Robert Paarlberg (2002) when reviewing the effects of the EU's position on GM crops, said the " real losers" were farmers in South East Asia and Southern Africa. Paarlberg further noted that the approval and subsequent success of Bt cotton in developing countries might be the first step toward the acceptance of other GM crops in those countries. Developing countries should not be

denied access to the new technologies by the international public and private sector community which pledged its support at Johannesburg and other summits, for a more sustainable agriculture, a better quality of life and alleviation of poverty for the poorest of the poor, which include millions of resource-poor cotton farmers. The challenge for the international community is to achieve sustainable growth with equity for the poorest of the poor in developing countries. The compelling case of providing more developing countries the option of sharing in the substantial environmental, health, economic and social benefits delivered by Bt cotton to millions of resource-poor cotton farmers in developing countries on millions of hectares over the last six years, embodies that challenge.

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APPENDIX

Table 1A. Latest Estimates for Seed Exports Worldwide, by Crop (US$ millions)

Crops	Seed Exports
Maize	530
Herbage crops	427
Potato	400
Beet	308
Wheat	75
Other Agricultural crops	750
Horticultural crops	1,150
Total	**3,640**

Source: FIS, 2001

Table 2A. Latest Estimates for Seed Exports: Major Exporting Countries (US$ millions)

Country	Agricultural Seeds	Horticultural Seeds	Total
USA	560	249	799
Netherlands	420	200	620
France	373	125	498
Denmark	150	40	190
Germany	150	35	185
Chile	84	60	144
Canada	104	18	122
Belgium	111	n.a.	111
Italy	70	41	111
Japan	5	100	105
Total	**2,027**	**868**	**32,895**

Source: FIS, 2001

US $25.00

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