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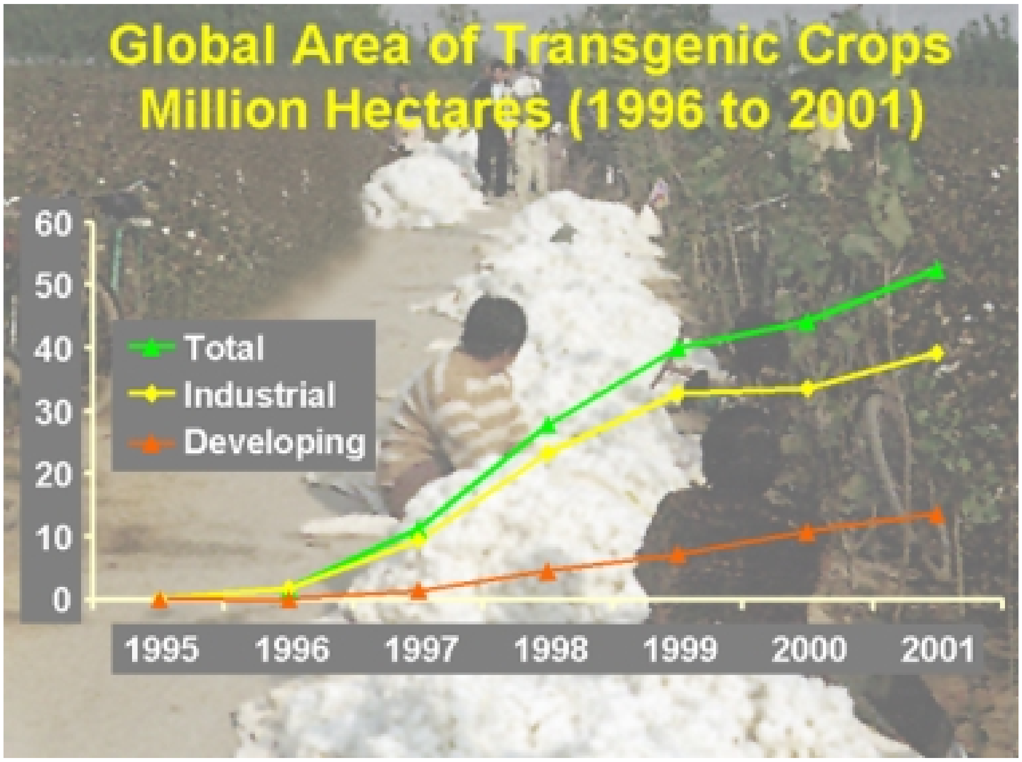
Global Review of Commercialized Transgenic Crops: 2001
Feature: Bt Cotton

by

Clive James
Chair, ISAAA Board of Directors



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CONTENTS

Executive Summary .... *iv*
List of Tables and Figures .... *x*

1. Introduction **1**

2. Overview of Global Review and Distribution of Commercial Transgenic Crops, 1996 to 2001 .... **4**

2.1 Distribution of Transgenic Crops in Industrial and Developing Countries 5
2.2 Distribution of Transgenic Crops, by Country 7
2.3 Distribution of Transgenic Crops, by Crop 9
2.4 Distribution of Transgenic Crops, by Trait 11
2.5 Dominant Transgenic Crops in 2001 13
2.6 Global Adoption of Transgenic Soybean, Maize, Cotton and Canola 14
2.7 Summary of Significant Changes between 2000 and 2001 15

3. Value of the Global Transgenic Seed Market, 1995 to 2001 .... **17**

4. Value of Transgenic Crops in the Context of the Global Crop Protection Market **18**

5. Global R&D Expenditures on Crop Biotechnology **22**

6. Overview of the Commercial Seed Industry **26**

7. Overview of Developments in the Crop Biotechnology Industry **28**

7.1 Alliances, Acquisitions, Spin-offs 28
7.2 Genomics and Product Discovery 29
7.3 Patents and Licensing 30
7.4 Re-registration, Approvals and Commercialization 31

8. Economic Benefits from GM Crops **40**

8.1 Economic Benefits of GM Crops in the USA 40

8.1.1 Benefits from the 8 GM crop varieties planted commercially in the US in 2001 40
8.1.2 Potential impact of GM crops approved but not deployed in US in 2001 42
8.1.3 Potential Impact of GM crops in the US that are under development for current and longer-term constraints 43

8.2 Economic Benefits from RR Soybean in Argentina 44
8.3 Benefits from Bt Corn in the Philippines 44

CONTENTS

8.4 Ex Ante Study on Potential Benefits of Golden Rice in the Philippines 45
8.5 Performance of Bt Maize in Spain 46
8.6 China's Investments in Crop Biotechnology 48

9. Bt Cotton 51

9.1 Introduction 51
9.2 The Cotton Crop 52
9.3 Global Distribution, Production, Consumption, Import and Exports 54
9.4 Number of Cotton Farmers Worldwide and Size of Farms 58
9.5 Insect Pests of Cotton 59
9.6 Crop Losses and Cost of Control 66
9.7 The Global Cotton Insecticide Market 69
9.8 The Use of *Bt* Genes in Cotton 70

9.8.1 Bollgard® and the Chinese Fusion Bt Gene 71
9.8.2 Bollgard® II cotton 72
9.8.3 Other expected new insect resistant cottons 75

9.9 Assessment of Risk 75

9.9.1 Assessment of Environmental Risk 75

9.9.1.1 Agronomic performance 75
9.9.1.2 The donor organisms 76
9.9.1.3 Effect on non-target organisms 76
9.9.1.4 Potential of Bt cotton to develop as a weed 77
9.9.1.5 Environmental consequences of pollen transfer 77

9.9.2 Insect Resistance Management (IRM) 78

9.10 Global Adoption of Cotton 82
9.11 Country Case Studies 85

9.11.1 USA 85
9.11.2 Australia 91
9.11.3 China 96
9.11.4 India 105
9.11.5 Mexico 118
9.11.6 Argentina 125
9.11.7 South Africa 129
9.11.8 Indonesia 135

CONTENTS

9.12 Agronomic, Environmental, Social and Economic Benefits 137

9.12.1 Agronomic Benefits 137

9.12.1.1 Yield advantage and improved pest control 137

9.12.2 Environmental Benefits 138

9.12.2.1 Reduction in use of cotton insecticides 138
9.12.2.2 Less insecticides in aquifers and the environment 142
9.12.2.3 Farmer exposure to insecticide and health implications 143
9.12.2.4 Reduced production risks and enhanced opportunities to grow Bt cotton 144
9.12.2.5 Increased populations of beneficial insects 145
9.12.2.6 Reduced risk for wildlife 146
9.12.2.7 Reduced fuel and raw material consumption, and pollution 146

9.12.3 Social Benefits 147

9.12.3.1 Social implication of saving by reducing number of insecticide sprays 147

9.12.4 Economic Benefits 150

9.12.4.1 China 151
9.12.4.2 USA 152
9.12.4.3 India 153
9.12.4.4 Other countries growing Bt cotton 154
9.12.4.5 Distribution of economic surplus to Bt cotton stakeholders 156

9.13 Global Potential of Bt Cotton: Challenges and Opportunities 158

Acknowledgments 172

References 173

Appendix 184

EXECUTIVE SUMMARY

Global GM Crop Area

- In 2001 global area of transgenic or GM crops was 52.6 million hectares or 130 million acres, grown in thirteen countries by about 5 million farmers, over 75% of whom were small resource-poor farmers in developing countries. The US was the largest grower of GM crops (68%), with one quarter of the GM crop area grown in the developing countries, principally in Argentina and China.

- The principal GM crops were soybean, corn, cotton and canola. On a global basis, 46% of the 72 million hectares of soybean was GM, 20% of the 34 million hectares of cotton, 11 % of the 140 million hectares of maize, and 11% of the 25 million hectares of canola.

- In the first six years of GM crop commercialization, 1996 to 2001, a cumulative total of over 175 million hectares of GM crops were planted globally which met the expectations of millions of small and large farmers in both industrial and developing countries.

- Global GM crop area is expected to continue to grow in 2002.

Value of the Global Transgenic Seed Market in 2001

- The value of the global transgenic seed market is based on the sale price of transgenic seed plus any technology fees that apply. The value in 2001 was $3.8 billion up from $3.0 billion in 2000.

Global R& D Expenditures in Crop Biotechnology in 2001

- Current global R&D expenditure in the private and public sectors is $4.4 billion with over 95% of the total in the industrial countries, led by the US. China is the leading investor in R&D crop biotechnology in the developing countries, followed by India.

Overview of the Commercial Seed Industry

- An overview of the $30 billion plus commercial seed industry is presented. Expressed as a proportion of the global commercial seed market, transgenic seed represented approximately 13% of the estimated $30 billion plus global commercial seed market in 2001.

Overview of Developments in the Crop Biotechnology Industry

- The major developments in crop biotechnology in the private sector in 2001 are summarized. Specific developments are discussed in each of four areas: acquisitions, mergers and spin-offs; genomics and product discovery; patents and licensing; and re-registration, approvals and commercialization.

Economic Benefits of GM Crops

- In the 2000 ISAAA Global Review of Transgenic Crops, an assessment was published of the global benefits associated with the principal GM crops - soybean, corn, cotton and canola. In the interim, several studies and surveys have been conducted and these are summarized to provide the reader with the current information on benefits from GM crops; these include an overview of the current and potential economic benefits of GM crops in the US, RR soybeans in Argentina, Bt maize in the Philippines and Spain and a review of the investments of China in crop biotechnology.

Feature for the 2001 Review: Bt Cotton

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 global potential for the future. 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.

- A total of 33.5 million hectares of cotton were grown globally in 2001, worth approximately $20 billion. Developing countries planted over 70% of the global area, and industrial countries grew 20%, mainly the USA (5.6 million hectares), as well as Australia, Greece and Spain. The remaining 10% was grown in Uzbekistan and other Central and West Asian countries. Asia has about 60% of world cotton, with India, China, and Pakistan dominating with 50% of global hectarage. Latin America grows <5% where Brazil is the only major grower. Africa has almost 15% of global cotton with 22 countries growing small (30,000 hectares) to modest (500,000 hectares) areas of cotton. There are approximately 20 million cotton farmers globally, 97% of whom farm in developing countries, 2% in Central and West Asian countries and <1% in the industrial countries. Most cotton growers in developing countries are small resource-poor farmers growing 2 hectares or less of cotton.

- Insect pests represent a major constraint to increased productivity in most cotton growing countries. The yield losses and the cost of controlling insect pests with insecticides costs cotton farmers an estimated $5 billion annually. The most important insect pests globally are the caterpillar moths – the lepidopteran pests - amongst which the 'bollworms' are the most damaging with losses and insecticide control costs totaling about $3 billion per year. Approximately 88% of the global cotton area suffer from medium to high infestation of lepidopteran pests. On a global basis, cotton farmers used $1.7 billion worth of insecticides in 2001 in their attempt to control cotton insect pests - more insecticides are applied to cotton than any other crop. Cotton consumes 20% of all insecticides applied to all crops globally.

- A novel method of controlling lepidopteran pests is the use of Bt genes from a soil bacterium, *Bacillus thuringiensis* (Bt). Bt genes have been incorporated in cotton through genetic engineering and were first introduced commercially in 1996 in the US and Australia in Bollgard® varieties. Bt cotton has been developed by private sector companies and deployed globally in nine countries. In China, the public sector has also released Bt cotton varieties, which compete with Bt cotton from the private sector. Since 1996 a total of nine countries, seven developing and two industrial countries have successfully grown 13 million hectares of Bt cotton. These include USA, Mexico, Argentina, and Colombia (pre-commercial) in the Americas, China, India, Indonesia and Australia in Asia and South Africa on the African continent.

- The potential development of resistance poses the biggest challenge to Bt cotton and the development and implementation of Insect Resistance Management (IRM) strategies is essential. Countries that have adopted Bt cotton have successfully implemented different IRM strategies and no resistance to Bt cotton has been detected to-date despite the fact that 13 million hectares of Bt cotton have been grown worldwide since 1996; several claims from critics proved to be unfounded. The recent approval in Australia of Bollgard II will considerably fortify IRM strategies because it has two independent Bt genes that confer resistance; other Bt and novel genes for cotton insect resistance are expected to be available by 2004. From a global viewpoint, any international initiative to substantially 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. An effective international mechanism to formulate, coordinate and oversee a global strategy for deploying Bt cotton responsibly and effectively could play a seminal role if it could be operated without onerous bureaucracy.

- Eight country case studies are presented which provide detailed and current information on all aspects of the cultivation, adoption and performance of Bt cotton, including an assessment of the agronomic, economic, environmental, health and social impact of the technology. Country studies are presented for the USA, Australia, China, India, Mexico, Argentina, South Africa and Indonesia which collectively have six years' experience with Bt cotton and grew almost 20 million hectares of cotton in 2001, equivalent to 60 % of the global hectarage of cotton.

- All countries that have introduced Bt cotton have derived significant and multiple benefits. These include increases in yield, decreased production costs, a reduction of at least 50% in insecticide applications, resulting in substantial environmental and health benefits to small producers, and significant economic and social benefits. In the US in 2001, the economic benefit from Bt cotton was estimated at $103 million or $50 per hectare. In China in 2001, Bt cotton increased yield on 1.5 million hectares and reduced insecticide use by 78,000 tons (formulated product) resulting in significantly fewer farmer insecticide poisonings. In 2001, Bt cotton in China increased annual farmer income by $500/hectare, equivalent to a national benefit of $750 million. Small resource-poor cotton farmers in the Makhathini Flats in South Africa, 50% of whom are women, derived similar benefits including significant social benefits devoting less time to carrying water and spraying insecticide and more time caring for children, attending to the sick, and family duties. To put a human face on the benefits of Bt cotton, for the average cotton holding of 1.7 hectares 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 per season, through using Bt cotton, rather than conventional cotton.

- Up to 5 million farmers benefited from Bt cotton in 2001, most of them small resource-poor farmers in developing countries, mainly in China and also in South Africa where Bt cotton contributed to the alleviation of poverty by increasing incomes of small farmers substantially. On a global basis, the benefits from the deployment of Bt cotton between 1998 and 2001 were estimated to be $1.7 billion.

- In terms of environmental impact, Bt cotton has resulted in a significant decrease in the volume of insecticides applied to cotton, which in turn reduced insecticide runoff into watersheds and aquifers. In the US alone for the three year period 1998, 1999 and 2001 the volume of insecticides applied to cotton was reduced by 2,979 MT (active ingredient). In China for the three period 1999 to 2001, insecticide tonnage on cotton was reduced by a substantial 123,000 MT of formulated product. Consequently, insecticide poisonings of cotton farmers, applying insecticides by hand with knapsacks, decreased by up to 75%. Similar evidence on insecticide poisonings has been reported for South Africa.

- Cotton is in many ways an ideal candidate for introduction to cotton-growing countries as the pilot and model GM crop. Its principal use as a fiber crop, rather than a food/feed-crop, facilitates its regulation and acceptance by the public at large. From a biosafety viewpoint it is a self pollinating tetraploid that will not outcross with native diploid cottons and the movement of the large pollen, which is not dispersed by wind, is limited to a few meters. Cotton is not found as a weed in the global production areas and Bt is unlikely to confer an advantage that would result in Bt cotton establishing as a weed. Thus, the potential biosafety consequences are negligible due to the limited movement of pollen, 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 is very unlikely to confer any competitive advantage. 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.

· To-date, only nine countries have adopted Bt cotton, which begs the question of what is the global potential for Bt cotton in the 50 key countries that grow cotton throughout the world. In the absence of field data to assess the performance of Bt cotton in the 50 countries, the projected saving in insecticide that would be associated with the use of Bt cotton can be used as an indicator of the potential of Bt cotton globally. The annual projected insecticide saving for the countries with medium to high infestations of lepidopteran pests is 33,000 MT valued at $690 million and equivalent to 37% of the 81,200 MT of cotton insecticides used globally in 2001. The gain of $690 million excludes the significant additional benefits that would accrue from reducing labor needs for insecticide sprays by half, plus the substantial additional income from the higher yields of Bt cotton. Potential annual global water savings, from optimizing the deployment of Bt cotton globally would reduce insecticide use by half, saving an estimated 6.3 billion liters of water (of which 1.7 billion liters have already been saved) or approximately 1.8 billion US gallons. 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

The six countries that have the potential for significant benefits from Bt cotton have either already adopted the technology, (China, India, USA and Australia) or are exploring its development (Pakistan and Brazil). The challenge is to provide the same opportunity for the potential beneficiary countries, with small to modest areas of cotton, in the developing world where several factors preclude access to Bt cotton. It is important that these smaller cotton-growing countries with resource-poor cotton farmers are offered the option of commercial access to Bt cotton so that they are not disadvantaged by being denied the significant benefits that accrue to adopters of the technology. There are 30 such developing countries, 21 in Africa, five in Asia and four in Latin America that grow small to modest areas of cotton that are potential beneficiaries of commercial Bt cotton but because of various constraints do not have the option to explore the potential benefits that Bt cotton offers in their own countries. The constraints range from absence of a regulatory framework that would allow field-testing of Bt cotton to determine its performance, lack of trained personnel, material and financial resources or the transaction cost may be too high for commercializing a relatively small area of cotton. Experience to-date in several developing countries has clearly demonstrated that Bt cotton can deliver significant economic, environmental, health and social benefits to small resource poor farmers that are assigned high priority by the donor community. Developing countries interested in evaluating Bt cotton and gaining commercial access to the technology in their own countries need assistance from the international public and private sector development community which pledged its support at Johannesburg, 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 compelling case for 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, represents a challenge for both the donor community and the developing countries which are the potential beneficiaries. Bt cotton presents a unique opportunity to utilize technology to contribute to the alleviation of poverty as proposed in the 2001 UNDP Human Development Report.

LIST OF TABLES AND FIGURES

TABLES

Table 1	Global Area of Transgenic Crops, 1996 to 2001	4
Table 2	Global Area of Transgenic Crops in 2000 and 2001: Industrial and Developing Countries	6
Table 3	Global Area of Transgenic Crops in 2000 and 2001: by Country	8
Table 4	Global Area of Transgenic Crops in 2000 and 2001: by Crop	11
Table 5	Global Area of Transgenic Crops in 2000 and 2001: by Trait	12
Table 6	Dominant Transgenic Crops, 2001	13
Table 7	Transgenic Crop Area as Percent of Global Area of Principal Crops, 2001	14
Table 8	Estimated Value of Global Transgenic Seed Market, 1995 to 2001 ($ millions)	17
Table 9	Global Crop Protection Market in 2001: by Product (Value in $ millions)	18
Table 10	Value of Global Transgenic Crops in 2001: by Crop and Region ($ millions)	19
Table 11	Global Crop Protection Market, 2001: by Industrial/Developing Country and Product ($ millions)	20
Table 12	Global Crop Protection Market, in 2001: by Country Expressed as Percentage of Total Market	21
Table 13	Global Crop Protection Market, in 2001: by Crop Expressed as Percentage of Total Market	21
Table 14	2000 Estimates of Global R&D Expenditures on Crop Biotechnology	24
Table 15	Global Value of Transgenic Crop Market 1996-2010	24
Table 16	Latest Estimated Values (US$ millions) of the Commercial Markets for Seed and Planting Material for the Top 20 Countries	26
Table 17	Selected Highlights of Crop Biotechnology Developments in Industry, 2001.............	33
Table 18	Impact of GM Crops planted in USA in 2001	40
Table 19	Potential Impact of GM Crops approved but not adopted in USA in 2001	42
Table 20	Summary of Current and Potential Gains for GM Crops in USA, 2001	43
Table 21	China's 26 GM crop applications (commercialized and in trials) in 2001	49
Table 22	Top 10 Cotton-Growing Countries by area, 2001-2002	54
	....	55
Table 23	Top 10 Producers of Lint Cotton in 2001-2002	56
Table 24	Top 10 Consumers of Lint Cotton in 2001-2002	57
Table 25	Top 10 Importers of Cotton 2001-2002	58
Table 26	Top 10 Exporters of Lint Cotton 2001-2002	
Table 27	Estimate of Number of Cotton Farmers Worldwide and Size	60
	of Cotton Holdings, 2001	
Table 28	Principal Lepidopteran Pests in the Major Cotton Producing	61
	Countries of the World	
Table 29	Global List of the 33 Countries Growing More than 100,000 hectares of Cotton in 2001-2002, Listing Insect Pests that can be of Major Importance and Average Number of Insecticide Sprays/Season	63

LIST OF TABLES AND FIGURES

Table 30 Lepidopteran Pest Infestation Levels and Cotton Area (000s of hectares) in the Top 50 Cotton-growing Countries 65
Table 31 Range of Actual and Potential Losses from Cotton Insect Pests for Different Global Regions 67
Table 32 Losses Due to Cotton Insect Pests in the US and Cost of Control by Insecticides and Other Means, 1994 to 2001 68
Table 33 Value of Global Cotton Insecticides at Farmer Level, 2001 70
Table 34 Estimated Level of Caterpillar Pest Control Provided by Bollgard® I Bt Cotton in the USA 72
Table 35 Relative Efficacy (Percent pest mortality) of Bollgard® and Bollgard® II 74
Table 36 Insect Resistance Management Strategy for Bollgard® Cotton 81
Table 37 Global Adoption of Bt cotton (Bt and Bt/Herbicide Tolerance), 1996 to 2001 (millions of hectares) 83
Table 38 Losses Due to Cotton Insect Pests in the US and Cost of Control by Insecticides and Other Means 86
Table 39 Adoption of Bt Cotton in the USA 88
Table 40 Lint Yields for Bt Cotton Varieties and Their Non–Bt Near Isogenic Parents 88
Table 41 US National Benefits from Bt Cotton 89
Table 42 Distribution of Economic Surplus from Bt Cotton in the USA (expressed as %) 90
Table 43 Adoption of Bt Cotton in Australia 92
Table 44 Yield (Bales/Hectare) of Bt Cotton Compared with Non-Bt Cotton in Australia 93
Table 45 Reduction in Number of Insecticide Sprays with Bt Cotton in Australia 93
Table 46 Insect Control Cost (A$/Hectare) for Bt Cotton and Non-Bt Cotton in Australia 93
Table 47 Production of Bt Cotton in China 1997-2001 99
Table 48 Insecticide Use on Bt and Non-Bt Cotton in China 1999-2001, Kg/Hectare of Formulated Product 100
Table 49 Percentage of Bt and Non-Bt Cotton Farmers Suffering from Pesticide Poisonings in China, 1999-2001 101
Table 50 Net Revenue (US$/Hectare) of Bt and Non-Bt Cotton Farmers in China 1999, 2000, 2001 (US$/Hectare) 102
Table 51 National Economic Benefits Associated with Bt Cotton in China 103
Table 52 Land Holdings, Distribution and Production Statistics of Cotton Farmers in India 106
Table 53 Summary of Bt Cotton Trials Conducted in India, 1998-1999 108
Table 54 Results of Field Trials and Economic Benefits of Bt Cotton in India 109
Table 55 Relative Agronomic and Economic Performance of Bt and Conventional Cotton in ICAR Field Trials in India in 2001 112
Table 56 Pest Control for Cotton in India 1998-2001 113
Table 57 Economic Advantage of Bt Cotton Versus Conventional Cotton in India in ICAR 2001 Field Trials 114
Table 58 Bt Cotton Area and Percent Adoption in Mexico, 1996-2001 119
Table 59 Area Planted to Bt Cotton by State, Mexico 2000 120

LIST OF TABLES AND FIGURES

Table 60 Lint Yield (MT/hectare) of Bt Cotton and Non-Bt Cotton in Mexico 1997 and 1998 ... 121
Table 61 Number and of Cost of Insecticide Applications on Bt Cotton and Non-Bt Cotton in Mexico ... 121
Table 62 Economic Advantage ($/Hectare) of Bt Cotton and Non-Bt Cotton in Mexico 1997 ... 122
Table 63 Economic Advantage ($/Hectare) of Bt Cotton and Non-Bt Cotton in Mexico 1998 ... 123
Table 64 Adoption of Bt Cotton in Argentina, 1998-2001 ... 126
Table 65 Comparison Between the Performance of Bt Cotton and Non-Bt Cotton in Argentina 1999-2000 and 2000-2001 ... 126
Table 66 Cotton Production in South Africa - 2001-2002 Production Year ... 130
Table 67 Area of Bt Cotton and Number of Bt Cotton Farmers in the Makhathini Flats, South Africa 1998-1999 to 2000-2001 ... 131
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 ... 131
Table 69 Advantages of Bt Cotton, Makhathini Flats, South Africa 1998-1999 and 1999-2000: Yield, Pesticide Use, Seed Cost and Gross Margins ... 131
Table 70 Savings Associated with Fewer Insecticide Sprays and Less Labor on Bt Cotton in South Africa, 2000-2001 ... 132
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 ... 132
Table 72 Economic Advantage (US$/Hectare) of Bt Cotton Versus Non-Bt Cotton for Small and Large Farmers in South Africa ... 133
Table 73 Performance of Bt Cotton in Indonesia, 2001 ... 136
Table 74 Global Yield Increases (%) in Bt Cotton in Selected Countries ... 138
Table 75 Increase in Lint Production due to Bt Cotton in USA ... 138
Table 76 Estimated Reduction in Number of Insecticide Sprays per Season for Bt Cotton in Selected Countries ... 139
Table 77 Reduction in Use of Cotton Insecticide in China 1999, 2000 and 2001 ... 140
Table 78 Estimates of Insecticide Reductions (MT of a.i.) Associated with Bt Cotton in 2001, based on 0.45 kg a.i per Hectare/Spray ... 142
Table 79 Estimates of Global Benefits from Bt Cotton 1998 to 2001 ($ millions) ... 156
Table 80 Distribution of Share of Economic Surplus from Transgenic Crops (Expressed as Percentage), for Different Stakeholders ... 157
Table 81 Estimated Potential Savings of Cotton Insecticide in 2001 (MT metric tons of Active Ingredient (a.i.)) in the Top 50 Cotton-growing Countries and Lepidopteran Pest Infestation Levels ... 159

LIST OF TABLES AND FIGURES

FIGURES

Figure 1 Global Area of Transgenic Crops, 1996 to 2001 5
Figure 2 Global Area of Transgenic Crops, 1996 to 2001: Industrial and Developing Countries 6
Figure 3 Global Area of Transgenic Crops, 1996 to 2001: by Country 9
Figure 4 Global Area of Transgenic Crops, 1996 to 2001: by Crop 10
Figure 5 Global Area of Transgenic Crops, 1996 to 2001: by Trait 12
Figure 6 Global Adoption Rates (%) for Principal Transgenic Crops, 2001 15
Figure 7 Global Adoption of Bt Cotton (Bt and Bt/Herbicide Tolerance), 1996 to 2001 (millions of hectares) 83

APPENDIX

Table 1A Latest Estimates for Seed Exports Worldwide: by Crop (US$ millions) 184
Table 2A Latest Estimates of Seed Exports: Major Exporting Countries (US$ millions) 184

1. INTRODUCTION

The unprecedented rapid adoption of transgenic crops during the initial five-year period, 1996 to 2000, when GM crops were first adopted, reflects the significant multiple benefits realized by large and small farmers in industrial and developing countries that have grown transgenic crops commercially. Between 1996 and 2000, a total of fifteen countries, 10 industrial and 5 developing, contributed to more than a twenty-five fold increase in the global area of transgenic crops from 1.7 million hectares in 1996 to 44.2 million hectares in 2000. The accumulated area of transgenic crops planted in the five-year period 1996 to 2000 total 125 million hectares, equivalent to more than 300 million acres.

Adoption rates for transgenic crops are unprecedented and are the highest for any new technologies by agricultural industry standards. High adoption rates reflect grower satisfaction with the products that offer significant benefits ranging from more convenient and flexible crop management, higher productivity and/or net returns per hectare, health and social benefits, and a safer environment through decreased use of conventional pesticides, which collectively contribute to a more sustainable agriculture. There is a growing body of evidence that clearly demonstrates the improved weed and insect pest control attainable with transgenic herbicide tolerant and insect resistant Bt crops, that also benefit from lower input and production costs; genetically modified (GM) crops offer significant economic advantages to farmers compared with corresponding conventional crops. The severity of weed and insect pests varies from year to year and hence this will directly impact on pest control costs and economic advantage.

Despite the on-going debate on GM crops, particularly in countries of the European Union, millions of large and small farmers in both industrial and developing countries continue to increase their plantings of GM crops year after year because of the substantial and multiple benefits they offer. This high adoption rate is a strong vote of confidence in GM crops, reflecting grower satisfaction. Many recent studies have confirmed that farmers planting herbicide tolerant and insect resistant Bt crops are more efficient in managing their weed and insect pests. An estimated 3.5 million farmers grew transgenic crops in 2000 and derived multiple benefits that included significant agronomic, environmental, health, social and economic advantages. In 2001, the number of farmers planting GM crops is expected to grow substantially and the global area of GM crops is expected to continue to grow. Global population exceeded 6 billion in 2000 and is expected to reach approximately 9 billion by 2050, when approximately 90% of the global population will reside in Asia, Africa and Latin America. Today, 815 million people in the developing countries suffer from malnutrition and 1.3 billion are afflicted by poverty. Transgenic crops, often referred to as genetically modified crops (GM), represent promising technologies that can make a vital contribution to global food, feed and fiber security.

The activities of ISAAA, the International Service for the Acquisition of Agri-biotech Applications in crop biotechnology transfer and the dissemination of information and knowledge is described by James (2001c). Global reviews of transgenic crops have been published by the author as ISAAA *Briefs* annually since 1996. This publication is the fifth by the author in the annual review series, to characterize and monitor the global status of commercialized transgenic crops. The first reviewed transgenic crops planted globally in 1996 (James and Krattiger 1996), the second for 1997 (James 1997a), the third for 1998 (James 1998); the fourth for 1999 comprised an early Preview (James 1999) followed by the annual Review for 1999 crops (James 2000a). The fifth for 2000 included a Preview (James 2000b) followed by the full annual Review for 2000 crops (James 2001a). The current publication presents the full annual global review of transgenic crops for 2001; a Preview (James 2001b) of this publication was published previously. This publication provides the latest information on the global status of commercialized transgenic crops for 2001. A detailed global data set on the adoption of commercialized transgenic crops is presented for the year 2001 and the changes that have occurred between 2000 and 2001 are highlighted. The global adoption trends during the last five years from 1996 to 2001 are also illustrated. The recent issues in relation to public acceptance of GM food as food aid in Africa has intensified the debate on transgenic crops.

The principal aim of this publication is to:

- provide an overview of the global adoption of transgenic crops in the period 1996 to 2001;
- document detailed information on the global status and distribution of commercial transgenic crops in 2001, by region, country, crop, and trait;
- rank the dominant transgenic crop/trait combinations in 2001;
- summarize and highlight the significant changes between 2000 and 2001;
- review the value of the transgenic seed market from 1995 to 2001 in the context of the global crop protection and seed market;
- provide current estimates of the global R & D expenditures in crop biotechnology;
- summarize the current status of the global commercial seed market;
- review crop biotechnology developments in the private sector, particularly the continuing alliances, acquisitions, and collaborations;
- review selected highlights for transgenic crops; and

- provide a comprehensive global overview of the experience with Bt cotton over the last six years since its introduction in 1996; the agronomic, environmental, economic and social benefits that it has delivered to date and its global potential in the future.

Note that the words maize and corn, rapeseed and canola, as well as transgenic and GM crops, are used synonymously in the text, reflecting the usage of these words in different regions of the world. Global figures and hectares planted commercially with transgenic crops have been rounded off to the nearest 100,000 hectares and in some cases this leads to insignificant approximations, and there may be slight variances in some figures, totals, and percentage estimates. It is also important to note that countries in the Southern Hemisphere plant their crops in the last quarter of the calendar year. The transgenic crop areas reported in this publication are planted, not harvested, hectarage in the year stated. Thus, the 2001 information for Argentina, Australia, South Africa and Uruguay is hectares planted in the last quarter of 2001 and harvested in the first quarter of 2002.

2. OVERVIEW OF GLOBAL STATUS AND DISTRIBUTION OF COMMERCIAL TRANSGENIC CROPS, 1996 TO 2001

Information on the adoption of commercial transgenic crops was provided by many independent sources from both the public and private sectors. Multiple sources of data, as well as additional and independent commercial marketing information, allowed several cross-checks to be conducted, which facilitated a rigorous verification of the estimates. For convenience and ease of interpretation, the data for the global status and distribution of commercial transgenic crops are presented in two complementary formats. Figures are used to best illustrate the changes in global transgenic area between 1996 and 2001. Companion tables provide more detailed corresponding information for 2001 and to illustrate the changes that have occurred between 2000 and 2001.

The estimated global area of transgenic crops for 2001 is 52.6 million hectares or 130.0 million acres (Table 1). It is noteworthy that 2001 is the first year when the global area of transgenic crops has exceeded the important historical milestone of 50 million hectares equivalent to approximately 125 million acres. To put this global area of transgenic crops into context, 52.6 million hectares is equivalent to more than 5% of the total land area of China (956 million hectares) or the US (981 million hectares) and more than twice the land area of the United Kingdom (24.4 million hectares). The increase in area of transgenic crops between 2000 and 2001 is 19%, equivalent to 8.4 million hectares or 20.8 million acres. This increase of 8.4 million hectares between 2000 and 2001 is almost twice the corresponding increase of 4.3 million hectares between 1999 and 2000 which was equivalent to an 11% growth.

Table 1. Global Area of Transgenic Crops, 1996 to 2001

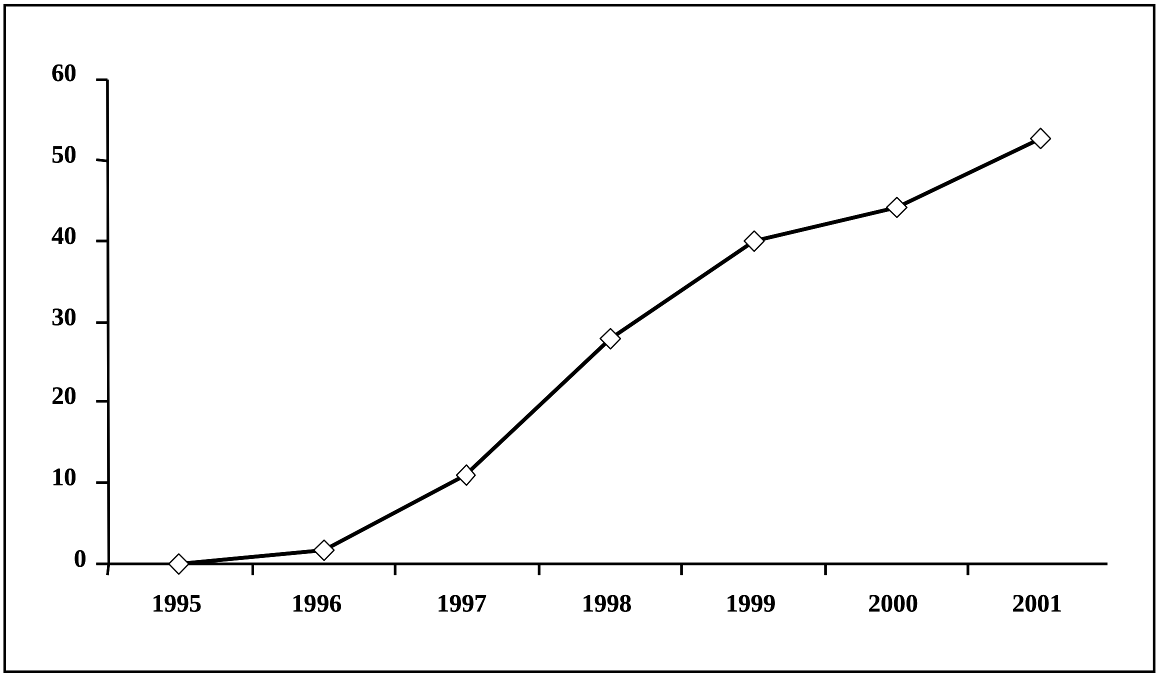
	Hectares (million)	**Acres** (million)
1996	1.7	4.3
1997	11.0	27.5
1998	27.8	69.5
1999	39.9	98.6
2000	44.2	109.2
2001	52.6	130.0

Increase of 19%, 8.4 million hectares or 20.8 million acres between 2000 and 2001.

Source: Clive James, 2002.

During the six-year period 1996 to 2001, the global area of transgenic crops increased by more than 30-fold, from 1.7 million hectares in 1996 to 52.6 million hectares in 2001 (Figure 1). This high rate of adoption reflects the growing acceptance of transgenic crops by farmers using the technology in both industrial and developing countries. During the six-year period 1996

Figure 1. Global Area of Transgenic Crops, 1996 to 2001 (Million Hectares).



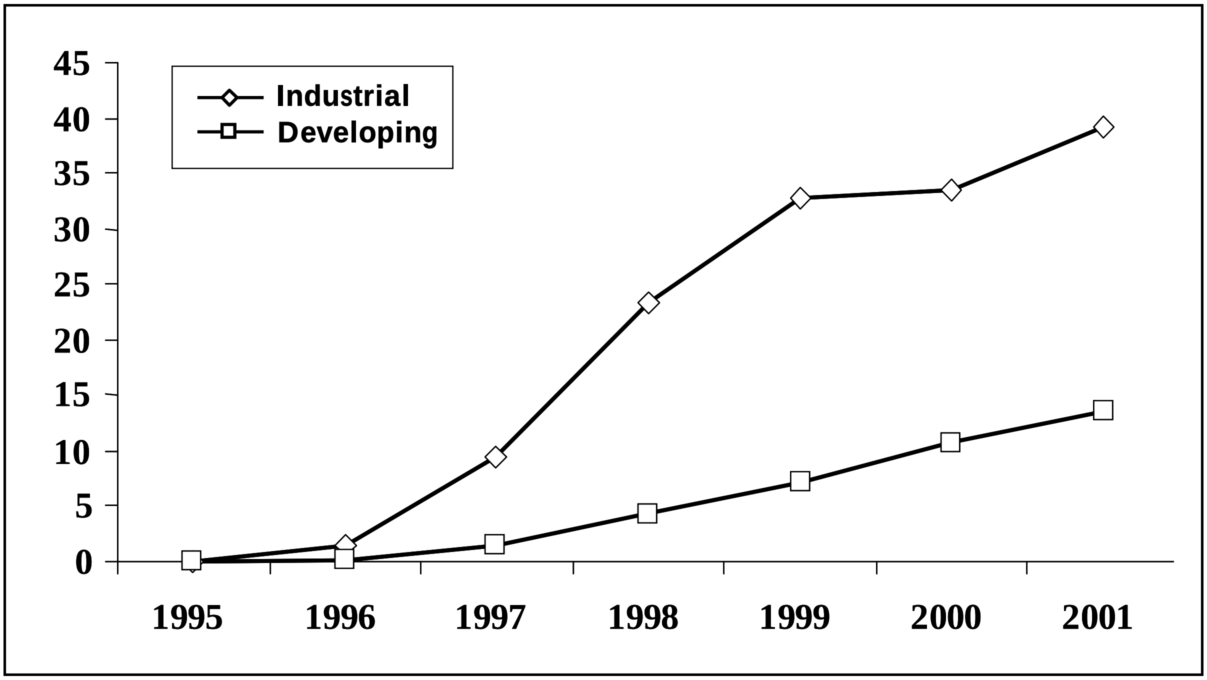
Source: Clive James, 2002.

– 2001, the number of countries growing transgenic crops more than doubled, increasing from 6 in 1996 to 9 in 1998, to 12 countries in 1999 and 13 in 2000 and 2001.

2.1 Distribution of Transgenic Crops in Industrial and Developing Countries

Figure 2 shows the relative hectarage of transgenic crops in industrial and developing countries during the period 1996 to 2001. It clearly illustrates that whereas the substantial share of GM crops have been grown in industrial countries, the proportion of transgenic crops grown in developing countries has increased consistently from 14% in 1997, to 16% in 1998, to 18% in 1999, 24% in 2000 and 26% in 2001. Thus, in 2001 more than one quarter (Table 2) of the global transgenic crop area of 52.6 million hectares, equivalent to 13.5 million hectares, was grown in developing countries where growth continued to be strong between 2000 and 2001. Whereas the absolute growth in GM crop area between 2000 and 2001 was twice as high in industrial countries (5.6 million hectares)

Figure 2. Global Area of Transgenic Crops, 1996 to 2001: Industrial and Developing Countries (Million Hectares).



Source: Clive James, 2002.

Table 2. Global Area of Transgenic Crops in 2000 and 2001: Industrial and Developing Countries (Million Hectares)

	2000	%	2001	%	+/-	%
Industrial Countries	33.5	76	39.1	74	+ 5.6	+ 17
Developing Countries	10.7	24	13.5	26	+ 2.8	+ 26
Total	**44.2**	**100**	**52.6**	**100**	**+ 8.4**	**+ 19**

Source: Clive James, 2002.

compared with developing countries (2.8 million hectares), the percentage growth was higher in the developing countries of the South (26%) than in the industrial countries of the North (17%).

2.2 Distribution of Transgenic Crops, by Country

In 2001, four countries grew 99% of the global transgenic crop area (Table 3), and all four countries reported growth of GM crops between 2000 and 2001 (Figure 3). It is noteworthy that the top four countries include two industrial countries, USA and Canada, and two developing countries, Argentina and China. Consistent with the pattern since 1996, the USA grew the largest transgenic crop hectarage (68%) in 2001. The USA grew 35.7 million hectares, followed by Argentina with 11.8 million hectares (22%), Canada 3.2 million hectares (6%) and China 1.5 million hectares (3%). China displayed the highest percentage year-on-year growth by tripling its GM crop area of Bt cotton between 2000 and 2001. Year-on-year growth was the same (18%) for the USA and Argentina and lower for Canada (6%). In 2001, transgenic crop hectarage also increased in South Africa and Australia where the growth rates were 33% and 37% respectively.

The 13 countries that grew transgenic crops in 2001 are listed in descending order of their transgenic crop areas (Table 3). There are 7 industrial countries and 6 developing countries. In 2001, transgenic crops were grown commercially in all six continents of the world – North America, Latin America, Asia, Oceania, Europe (Eastern and Western), and Africa. Of the top four countries that grew 99% of the global transgenic crop area, the USA grew 68%, Argentina 22%, Canada 6% and China 3%. The other 1% was grown in the remaining 9 countries, with South Africa and Australia being the only countries in that group growing more than 100,000 hectares or a quarter million acres of transgenic crops.

In the USA there was an estimated net gain of 5.4 million hectares of transgenic crops in 2001; this came about as a result of significant increases in the area of transgenic soybean and cotton, a modest increase in canola, and a small decrease in the area of transgenic corn. In Argentina, a gain of 1.8 million hectares was reported for 2001 because of significant growth in transgenic soybean and a modest increase in corn.

For Canada, a net gain of 0.2 million hectares was estimated with gains in both GM corn and soybean with a slight decrease in GM canola associated with the general decrease of 856,000 hectares in the national area planted to canola in 2001 compared with 2000. For China, the area planted to Bt cotton increased by a significant 1.0 million hectares from 0.5 million hectares in 2000 to 1.5 million hectares in 2001.

A significant increase of Bt corn was reported for South Africa, where the combined area of transgenic corn and cotton and soybean is expected to be approximately 225,000

Table 3. Global Area of Transgenic Crops in 2000 and 2001: by Country (Millions of Hectares)

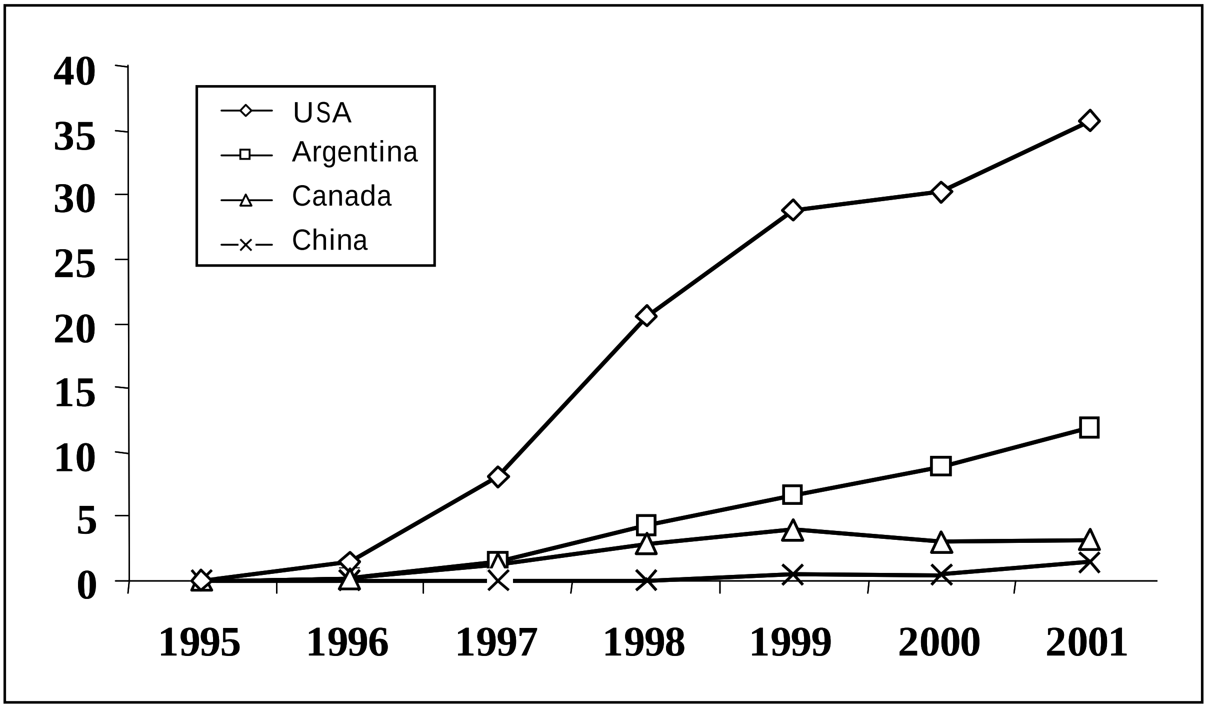
Country	2000	%	2001	%	+/-	%
USA	30.3	68	35.7	68	+ 5.4	+ 18
Argentina	10.0	23	11.8	22	+ 1.8	+ 18
Canada	3.0	7	3.2	6	+ 0.2	+ 6
China	0.5	1	1.5	3	+ 1.0	+ 200
South Africa	0.2	<1	0.2	<1	< 0.1	+ 33
Australia	0.2	<1	0.2	<1	< 0.1	+ 37
Mexico	<0.1	<1	<0.1	<1	< 0.1	- -
Bulgaria	<0.1	<1	<0.1	<1	< 0.1	- -
Uruguay	<0.1	<1	<0.1	<1	< 0.1	- -
Romania	<0.1	<1	<0.1	<1	< 0.1	- -
Spain	<0.1	<1	<0.1	<1	< 0.1	- -
Indonesia	- -	- -	<0.1	<1	< 0.1	- -
Germany	<0.1	<1	<0.1	<1	< 0.1	- -
France	<0.1	<1	- -	- -	- -	- -
Total	**44.2**	**100**	**52.6**	**100**	**+ 8.4**	**+ 19%**

Source: Clive James, 2002.

hectares. In Australia, over 200,000 hectares of transgenic cotton was planted in 2001 compared with 150,000 hectares in 2000, with Mexico reporting a modest area of transgenic cotton and soybean. The countries growing transgenic crops in 2001 include two Eastern European countries, Romania growing soybean, and Bulgaria growing herbicide tolerant corn. The two European Union countries – Spain and Germany – which grew small areas of Bt corn in 2000, continued to grow Bt corn in 2001 – Spain grew about 12,000 hectares and Germany less than a hundred hectares in 2001. France, which grew a token area of Bt corn in 2000, did not report any Bt corn for 2001. One new GM country, Indonesia, reported the commercialization of transgenic crops for the first time in 2001, growing a small area, 4,000 hectares, of Bt cotton.

The country portfolios of deployed GM crops continued to diversify in 2001 with several crop/trait introductions reported for the first time. These included: herbicide tolerant corn in Argentina; herbicide tolerant cotton as well as the stacked Bt/herbicide tolerant cotton in Australia; herbicide tolerant soybean, Bt white corn and herbicide tolerant cotton in South Africa and Bt cotton in Indonesia.

Figure 3. Global Area of Transgenic Crops, 1996 to 2001: by Country (Million Hectares).



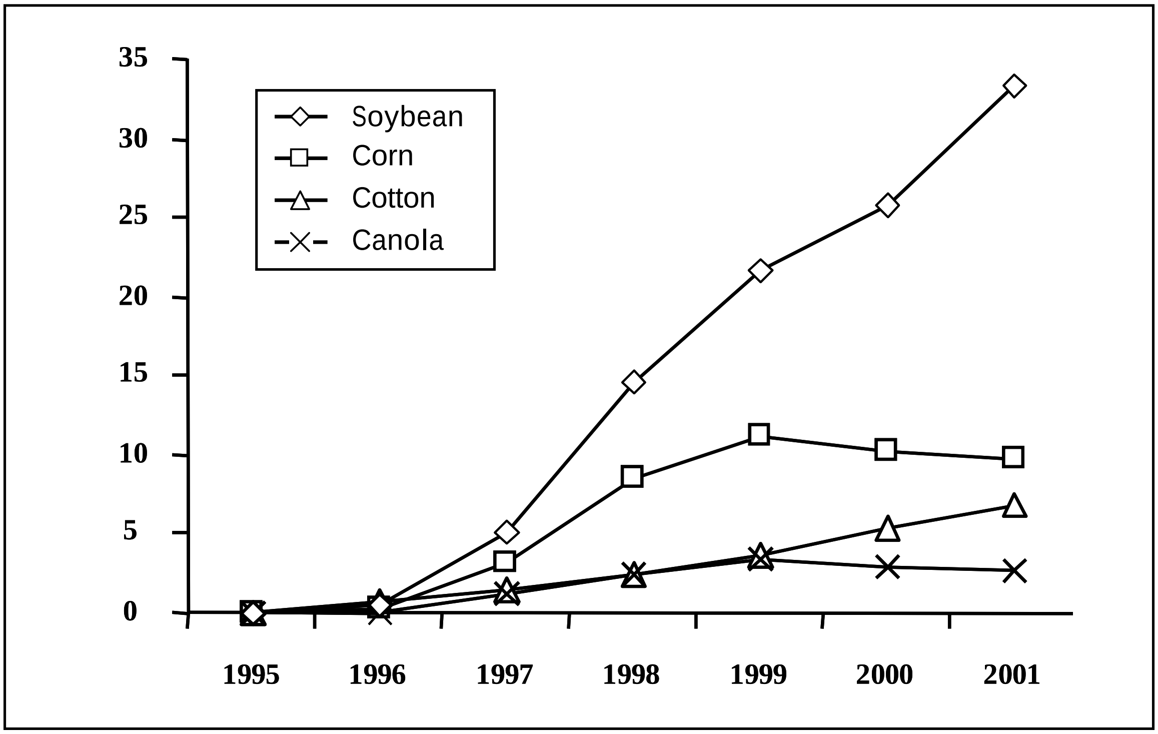
Source: Clive James, 2002.

2.3 Distribution of Transgenic Crops, by Crop

The distribution of the global transgenic crop area for the four major crops is illustrated in Figure 4 for the period 1996 to 2001. It clearly shows the dominance of transgenic soybean occupying 63% of the global area of transgenic crops in 2001; the entire transgenic soybean is herbicide tolerant. Transgenic soybean retained its position in 2001 as the transgenic crop occupying the largest area. Globally, transgenic soybean occupied 33.3 million hectares in 2001, with transgenic corn in second place at 9.8 million hectares, transgenic cotton in third place at 6.8 million hectares, and canola at 2.7 million hectares (Table 4).

In 2001, the global hectarage of herbicide tolerant soybean is estimated to have increased by 7.5 million hectares, equivalent to a 29% increase. Gains of approximately 5.7 million hectares of transgenic soybean were reported for the USA in 2001 with 71% of the national soybean area of 30.1 million hectares planted to GM crops. Argentina reported a gain of 1.8 million hectares of GM soybean with adoption rates estimated at 98% of the 11.2 million hectares of soybeans grown in 2001.

Figure 4. Global Area of Transgenic Crops, 1996 to 2001: by Crop (Million Hectares).



Source: Clive James, 2002.

Transgenic corn area in 2001 is estimated to have decreased globally by about 500,000 hectares (Table 4) with all the reduction in the USA. Some observers have attributed the reason for the decrease in transgenic corn in the USA in 2001 to some farmers concluding that the historically low infestations of European Corn Borer in 1999 and 2000 did not merit the use of Bt corn in 2001 on the basis that infestation may continue to be low; however ECB levels in 2001 proved to be much higher than expected and this may result in increased plantings of Bt corn in 2002. Others have suggested that some farmer uncertainty about markets for transgenic corn as well as low prices may have contributed to decreased plantings of Bt corn in 2001 by a small proportion of farmers. Decreases in transgenic corn in the USA were offset by significant increases in transgenic corn in Canada, Argentina and South Africa where adoption rates increased.

The small decrease of 100,000 hectares in area planted globally with transgenic canola in 2001 all occurred in Canada and was associated with the general decrease of 856,000 hectares in the national area planted to canola in Canada in 2001 compared with 2000. However, the percentage of the canola

Table 4. Global Area of Transgenic Crops in 2000 and 2001: by Crop (Millions of Hectares)

Crop	2000	%	2001	%	+/-	%
Soybean	25.8	58	33.3	63	+7.5	+29
Maize	10.3	23	9.8	19	-0.5	-5
Cotton	5.3	12	6.8	13	+1.5	+28
Canola	2.8	7	2.7	5	-0.1	-4
Potato	<0.1	<1	<0.1	<1	<0.1	- -
Squash	<0.1	<1	<0.1	<1	(- -)	- -
Papaya	<0.1	<1	<0.1	<1	(- -)	- -
Total	**44.2**	**100**	**52.6**	**100**	**+ 8.4**	**+ 19**

Source: Clive James, 2002.

crop in Canada planted to transgenics increased from 55% in 2000 to 61% in 2001. The decrease in Canada in 2001 was offset by a modest increase in transgenic canola in the USA which increased by more than 10% in 2001.

The global area of transgenic cotton in 2001 is estimated to have increased by 1.5 million hectares, from 5.3 million hectares in 2000 to an estimated 6.8 million hectares in 2001 – this is equivalent to a year-over-year increase of 28% in the global area of transgenic cotton. The most significant increase was reported for China which tripled its Bt cotton area from 0.5 million hectares in 2000 to 1.5 million hectares in 2001. In the USA the percentage of transgenic cotton increased from 72% in 2000 to 77% in 2001. Australia also increased its transgenic cotton area by 33% from 150,000 to 200,000 hectares with plantings at approximately the same levels in Mexico, Argentina, and South Africa.

2.4 Distribution of Transgenic Crops, by Trait

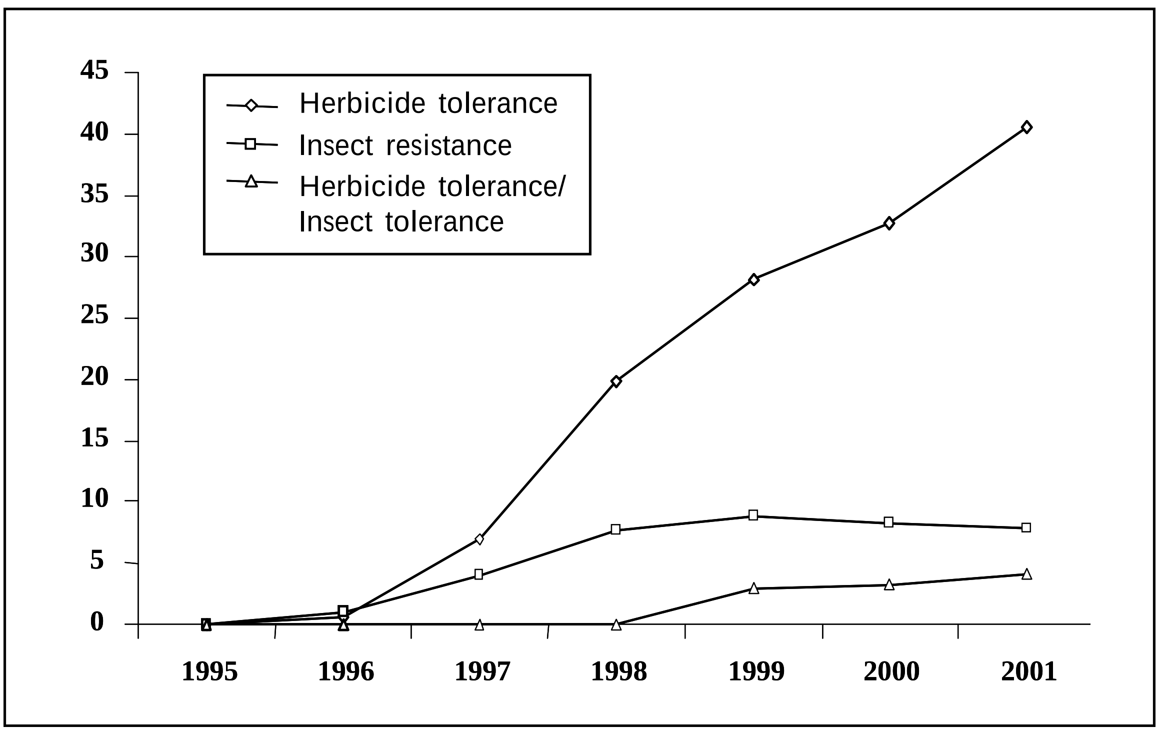
During the six-year period 1996 to 2001, herbicide tolerance has consistently been the dominant trait with insect resistance being second (Figure 5). In 2001, herbicide tolerance, deployed in soybean, corn and cotton, occupied 77% of the 52.6 million hectares (Table 5), with 7.8 million hectares planted to Bt crops equivalent to 15%, and stacked genes for herbicide tolerance and insect resistance deployed in both cotton and

Table 5. Global Area of Transgenic Crops in 2000 and 2001: by Trait (Millions of Hectares).

Trait	2000	%	2001	%	+/-	%
Herbicide tolerance	32.7	74	40.6	77	+ 7.9	+ 24
Insect resistance (Bt)	8.3	19	7.8	15	- 0.5	- 6
Bt/Herbicide tolerance	3.2	7	4.2	8	+ 1.0	+ 31
Virus resistance/Other	<0.1	<1	<0.1	<1	< 0.1	- -
Global Totals	**44.2**	**100**	**52.6**	**100**	**+8.4**	**19**

Source: Clive James, 2002.

Figure 5. Global Area of Transgenic Cops, 1996 to 2001: by Trait (Million Hectares).



Source: Clive James, 2002.

corn occupying 8% of the global transgenic area in 2001. It is noteworthy that the area of herbicide tolerant crops has increased significantly by 24% or 7.9 million hectares between 2000 and 2001 (32.7 million hectares to 40.6 million hectares). Crops with stacked genes for herbicide tolerance and Bt also increased from 3.2 million hectares in 2000 to 4.2 million hectares in 2001, whereas the global area of insect resistant crops has decreased from 8.3 million hectares in 2000 to 7.8 million hectares in 2001 (Table 5 and Figure 5). The trend for stacked genes to gain an increasing share of the global transgenic crop market is expected to continue.

2.5 Dominant Transgenic Crops in 2001

Herbicide tolerant soybean was the most dominant transgenic crop grown commercially in seven countries in 2001 – USA, Argentina, Canada, Mexico, Romania, Uruguay and South Africa (Table 6). Globally, herbicide tolerant soybean occupied 33.3 million hectares, representing 63% of the global transgenic crop area of 52.6 million hectares for all crops. The second most dominant crop was Bt maize, which occupied 5.9 million hectares, equivalent to 11% of global transgenic area and planted in six

Table 6. Dominant Transgenic Crops 2001

Crop	Million Hectares	% Transgenic
Herbicide tolerant Soybean	33.3	63
Bt Maize	5.9	11
Herbicide tolerant Canola	2.7	5
Herbicide tolerant Cotton	2.5	5
Bt/Herbicide tolerant Cotton	2.4	5
Herbicide tolerant Maize	2.1	4
Bt Cotton	1.9	4
Bt/Herbicide tolerant Maize	1.8	3
Total	**52.6**	**100**

Source: Clive James, 2002.

countries – USA, Canada, Argentina, South Africa, Spain, and Germany. The other six crops listed in Table 6 all occupy 5% or less of global transgenic crop area and include, in descending order of area: herbicide tolerant canola, occupying 2.7 million hectares (5%); herbicide tolerant cotton on 2.5 million hectares (5%); Bt/herbicide tolerant cotton on 2.4 million hectares (5%); herbicide tolerant maize on 2.1 million hectares (4%); Bt cotton on 1.9 million hectares (4%); and Bt/herbicide tolerant maize on 1.8 million hectares (3%).

2.6 Global Adoption of Transgenic Soybean, Corn, Cotton and Canola

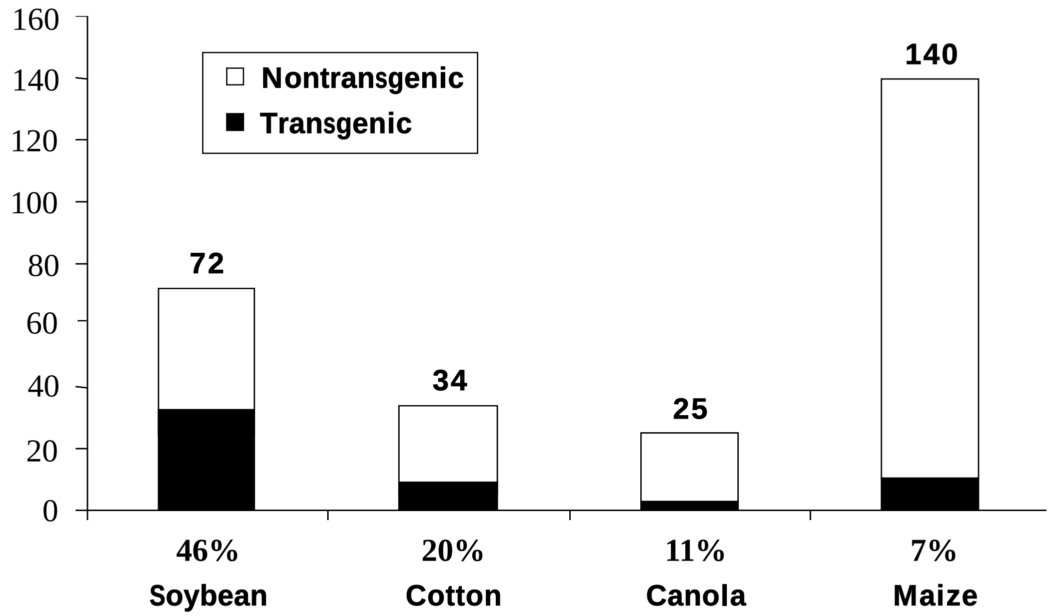
One useful way to portray a global perspective of the status of transgenic crops is to characterize the global adoption rates of the four principal crops – soybean, cotton, canola and corn – in which transgenic technology is utilized (Table 7 and Figure 6). The data indicates that in 2001, 46% of the 72 million hectares of soybean planted globally were transgenic - up from 36 % in 2000. Similarly, 20% of the 34 million hectares of cotton up from 16 % in 2000 were planted to transgenic cotton. The areas planted to transgenic canola and maize, expressed on percentage basis, were unchanged at 11% of the 25 million hectares of canola, and 7% of the 140 million hectares of maize respectively. If the global areas (conventional and transgenic) of these four crops are aggregated, the total area is 271 million hectares, of which 19%, up from 16% in 2000, is genetically modified. It is noteworthy that two-thirds of these 271 million hectares are in the developing countries where yields are lower, constraints are greater, and the need for improved production of food, feed, and fiber crops is the greatest.

Table 7. Transgenic Crop Area as % of Global Area of Principal Crops, 2001 (Million Hectares)

Crop	Global Area	Transgenic Crop Area	Transgenic Area as % of Global Area
Soybean	72	33.3	46
Cotton	34	6.8	20
Canola	25	2.7	11
Maize	140	9.8	7
Others	-	-	-
Total	**271**	**52.6**	**19**

Source: Clive James, 2002.

Figure 6. Global Adoption Rates (%) for Principal Transgenic Crops, 2001 (Million Hectares)



Source: Clive James, 2002.

2.7 Summary of Significant Changes between 1999 and 2001

The major changes in area and global share of transgenic crops for the respective countries, crops, and traits, between 2000 and 2001 were related to the following factors:

- In 2001, the global area of transgenic crops increased by 19%, or 8.4 million hectares, to 52.6 million hectares, from 44.2 million hectares in 2000. Eight transgenic crops were grown commercially in 13 countries in 2001, one of which, Indonesia grew a transgenic crop, Bt cotton, for the first time. France, which grew a small area of Bt maize in 2000 did not report transgenic crops in 2001.

- The four principal countries that grew the majority of transgenic crops in 2001 were USA 35.7 million hectares (68% of the global area); Argentina, 11.8 million hectares (22%), Canada 3.2 million hectares (6%); China 1.5 million hectares (3%). The balance was grown in South Africa, Australia, Mexico, Bulgaria, Uruguay, Romania, Spain, Indonesia and Germany. The highest growth in transgenic crop area between 2000 and 2001 was reported for the USA (5.4 million hectares), followed by Argentina (1.8 million hectares), China (1.0 million hectares) and Canada with 0.2 million hectares.

- In the developing countries growth in area of transgenic crops between 2000 and 2001 was 26% compared with 17 % in industrial countries, whereas absolute growth in area was twice as high in industrial countries (5.6 million hectares) compared with 2.8 million hectares in developing countries.

- In terms of crops, soybean contributed the most to global growth of transgenic crops, equivalent to 5.7 million hectares between 2000 and 2001, followed by cotton with an increase of 1.5 million hectares. Corn and canola decreased by 0.5 and 0.1 million hectares respectively because of decreases in USA and Canada, which were partly offset by increases in transgenic corn in developing countries.

- There were three noteworthy developments in terms of traits; herbicide tolerance contributed the most (7.9 million hectares) to global growth between 2000 and 2001; the stacked genes of insect resistance and herbicide tolerance in both corn and cotton contributed 1.0 million hectares, with insect resistance decreasing by 0.5 million hectares.

- Of the 4 major transgenic crops grown in 13 countries in 2001, the two principal crops of soybean and corn represented 63% and 19% respectively for a total of 82% of the global transgenic area, with the remaining 18% shared between cotton (13%) and canola (5%).

- In 2001, herbicide tolerant soybean was the most dominant transgenic crop (63% of global transgenic area, compared with 59% in 2000), followed by insect resistant maize (11% compared with 15% in 2000), herbicide tolerant canola and cotton and Bt/herbicide tolerant cotton all at 5%, herbicide tolerant maize and Bt cotton at 4% and Bt/herbicide tolerant maize at 3%.

The combined effect of the above seven factors resulted in a global area of transgenic crops in 2001 that was 8.4 million hectares greater and 19% more than 2000. This is a significant year-on-year increase considering the high percentage of the principal crops already planted to transgenics in 2000.

3. VALUE OF THE GLOBAL TRANSGENIC SEED MARKET, 1995 TO 2001

The value of the transgenic crop market is based on the sale price of transgenic seed plus any technology fees that apply. The estimates published here are the most recently revised estimates from Wood Mackenzie Agrochemical Services (Wood Mackenzie 2002) which exclude non-genetically modified herbicide tolerant seed. Global sales of transgenic seed have grown rapidly from 1995 onwards (Table 8). Initial global sales of transgenic seed were estimated at $ 1 million in 1995. Sales increased in value to $ 148 million in 1996, and increased by approximately $ 711 million in 1997 to reach $ 859 million. Sales increased by another $1,111 million between 1997 and 1998 to reach $ 1.97 billion in 1998. Sales continued to increase substantially in 1999 by an additional $ 977 million to reach $2.95 billion in 1999 and in 2000 plateaued at $ 3,044 million. In 2001 there was a renewed significant increase of $795 million to $3.8 billion.

Table 8. Estimated Value of Global Transgenic Seed Market, 1995-2001 ($ Millions)

Year	Market Value $
1995	1
1996	148
1997	859
1998	1,970
1999	2,947
2000	3,044
2001	**3,839**

Source: Wood Mackenzie, 2002 (Personal Communication)

4. VALUE OF TRANSGENIC CROPS IN THE CONTEXT OF THE GLOBAL CROP PROTECTION MARKET

All the traits introduced to-date are crop protection traits, and thus it is useful and appropriate to discuss the value of total sales of transgenic crops as a percentage of the global crop protection market. Wood Mackenzie (2002) estimated that transgenic seed in 1998 accounted for 6.3% of the $31.25 billion global crop protection market at the ex-distributor market value. Between 1998 and 2001 the value of the transgenic seed market has increased steadily from 6.3% in 1998 to 9.5% in 2000, and to 12.4 % in 2001 (Table 9) equivalent to $ 3.839 billion out of a total crop protection market of $30.943 billion. It is noteworthy that the transgenic crops category is the only one of the five categories to show an increase in value between 2000 and 2001 (Table 9); transgenic crops increased by a significant 26.1%, whilst herbicides decreased by 6.9%, insecticides by -6.1% and fungicides by -6.9%.

The distribution of the sale of transgenic seed, based on value, is shown by region and product in Table 10. It is clear that the major market is in North America with its share valued at $ 2.865 billion equivalent to 60% of the global market; the second largest market is in Latin America with $766 million equivalent to 20% of the global market, followed by the Far East (developing countries of Asia) at $195 million or 5% of global market share. In terms of product, soybean has the major market share at $2.194 billion or 57% of the global market followed by maize at $ 783 million (20%), cotton at $ 636 million (17%) and canola $226 million (6%).

Table 9. Global Crop Protection Market in 2001: by Product (Value in $ Millions)

Group	$ Millions	% Change from 2000
Herbicides	12,885	- 6.9%
Insecticides	7,559	- 6.1%
Fungicides	5,306	- 6.9%
Plant Growth Regulators and Others	1,354	- 3.3%
Transgenic Crops	3,839	+ 26.1%
Total	**30,943**	**- 5.7%**

Source: Wood Mackenzie Agrochemical Services, 2002 (Personal Communication).

Table 10. Value of Global Transgenic Crops in 2001: by Crop and Region ($ Millions)

Crop	$ Millions
Soybean	2,194
Maize	783
Cotton	636
Canola	226
Total	**3,839**
Region	
North America	2,865
Latin America	766
West Europe	<2
East Europe	<3
Far East	195
Rest of the World	10
Total	**3,839**

Source: Wood Mackenzie, 2002 (Personal Communication).

The data in Table 11 is a matrix of crop protection products, including GM biotech traits deployed in industrial and developing countries. It shows the relative distribution between industrial and developing countries in relation to the different types of pesticides. It is noteworthy that the value of the transgenic crop market in USA and Canada ($2.865 billion, Table 10) is already worth 9% of the global crop protection market of $31 billion and continues to grow annually – this compares with 2% for Latin America ($766 million), and <1% for the developing countries of the Far East. It is evident from the data in Table 11 that the value of the transgenic crop market is higher in the industrial countries, $2.869 billion equivalent to 59% of the global market, compared with $970 million, equivalent to 25%, in the developing countries, over 78% of which is in Latin America and with most of the balance in the Far East.

Of the total crop protection market of $19.656 billion in the industrial countries, $2.869 billion equivalent to 15% is transgenic crops. The corresponding figure for the developing countries is a total crop protection market of $11.287 billion of which transgenic crops are valued at $970 million equivalent to 9%, up from 5% in 2000. Whereas, the value of the herbicide market in the industrial countries ($ 8.6 billion) is twice that in the developing countries ($4.3 billion), the countries of the South spend more on insecticides ($3.9 billion) than the countries in the North ($3.6 billion). However, the significant difference in herbicide usage between industrial and developing countries is likely to become less marked in the future. Agronomic practices such as zero or low–tillage, availability and cost of labor in developing countries will offer new opportunities for farmers to use more herbicide tolerant varieties, that allow improved conservation of moisture and nutrients that collectively contribute to a more sustainable agriculture. Efficient use of water in both rainfed and irrigated agriculture will become increasingly important and herbicide

Table 11. Global Crop Protection Market, 2001: by Industrial/Developing Country and Product ($ Millions)

	Herbicides	Insecticides	Fungicides	Others	Biotech	Total
Industrial Countries	8,624	3,616	3,556	991	2,869	**19,656**
Developing Countries	4,261	3,943	1,750	363	970	**11,287**
Total	**12,885**	**7,559**	**5,306**	**1,354**	**3,839**	**30,943**

Source: Wood Mackenzie, 2002 (Personal Communication).

tolerance technology will be seen by farmers to be compatible with changing and emerging new needs.

Of the total global crop protection market of $31 billion, about two-thirds is in the industrial countries ($19.656 billion) with the other one-third ($11.287 billion) in the developing countries (Table 11). The data in Table 12 indicate the global market share of the 12 principal countries in crop protection; the balance is assigned to the remaining “Others” category. Of the top 12 countries, eight are industrial countries (USA, Japan, France, Canada, Germany, South Korea, Australia and Italy) and four are developing countries (Brazil, China, Argentina and India). Expressed as a percentage of the global market, there are five countries with 5% or more of global market share.

The US is by far the biggest crop protection market (32% of the global $31 billion market), followed by Japan (9%), Brazil (8%), China (6%), and France (5%). The remaining seven countries listed in Table 12 have global market shares of between 2% and 5%. It is not surprising that the top four countries that grew 99% of the transgenic crops in 2001 (USA, Argentina, Canada, and China) are also in the top ten in the global crop protection market. Collectively the top four countries that grew transgenics in 2001 consumed 45% of the global pesticide market and are already benefiting from reduced and/or more efficient pesticide usage. Similarly, the four major transgenic crops, soybean, maize, cotton and canola include three out of the top five crops that consume pesticides globally (Table 13). Collectively, the four crops consume 38% of global pesticides and are already benefiting from reduced and/or more efficient pesticide usage, particularly in crops such as Bt cotton where major reductions are being realized in terms of insecticides and fewer health hazards to farmers in countries such as China and South Africa. Further reductions and increase in efficiencies in pesticide usage can be realized as more insect resistant crops and herbicide tolerant varieties are deployed. Coincidentally, these technologies will provide major benefits in terms of more flexible and improved

Table 12. Global Crop Protection Market, in 2001: by Country Expressed as Percentage of Total Market

Country	% Global Market
USA	32
Japan	9
Brazil	8
China	6
France	5
Argentina	4
Canada	3
Germany	3
South Korea	3
Australia	2
India	2
Italy	2
Others	21
Total	**100**

Source: Wood Mackenzie, 2002 (Personal Communication).

Table 13. Global Crop Protection Market, in 2001: by Crop Expressed as Percentage of Total Market

Total Crop Protection Market by Crop	%
Fruit and Vegetables	24
Soybeans	15
Cereals	13
Maize	11
Cotton	10
Rice	9
Oilseed Rape/Canola	2
Sugar Beet	2
Other Crops	14
Total	**100**

Source: Wood Mackenzie, 2002 (Personal Communication).

conservation and management practices that farmers value highly and which collectively contribute to more sustainable farming systems.

It is noteworthy that the increase in the developing country GM crop market from $671 million in 2000 to $970 million is a 44% increase and significantly greater than the corresponding 20% increase in industrial countries from $2.373 billion to $ 2.869 billion. The significant increase in developing countries reflected a 41% increase in the value of the transgenic market in Latin America, and a 79% increase in Asia.

5. GLOBAL R&D EXPENDITURES IN CROP BIOTECHNOLOGY AND FUTURE GM CROP MARKETS

The advent of biotechnology in the early 1980s resulted in a significant change in the relative R&D investments of the public and private sectors in agriculture. Estimates of R&D investments in agricultural biotechnology in 1985 (Persley 1990) indicated that the total annual investments were $900 million with $550 million (61%) invested by the private sector and $350 million (39%) by the public sector. The life sciences concept embraced by the private sector in the early 1990s, which resulted in a spate of expensive acquisitions and mergers significantly increased the investment of industry in agricultural biotechnology. In 1995, R&D investment in agricultural biotechnology was $2 billion for the USA alone (James 1997b) and globally at $2.75 billion. Public sector investments in crop biotechnology continue to be substantial in the USA in 2001 and remain dominant in the global context. Australia is also committed to its public sector investments in crop biotechnology and three EU countries, UK, Germany and France, continue to support crop biotechnology. In Asia, Japan and South Korea have modest public sector investments in crop biotechnology (Kalaitzandonakes 2000).

In 1995 the private sector viewed crop biotechnology, prior to the commercialization of the first GM crops in 1996, as an important new opportunity for markets that would contribute to lowering crop production costs, increasing productivity, provide a safer environment and a more sustainable system for ensuring global food, feed and fiber security. Later in the 1990s the private sector judged the life science concept to be an inappropriate strategy for the future. There followed a series of spin-offs and mergers culminating in consolidation that resulted in six transnational North American and European based crop protection/ biotechnology entities. By the late 90s, the rate of investments in R&D by the private sector in GM crops was slowing despite the fact that the technology had a great deal to offer society. The disincentive for industry was mainly the reluctance and strong opposition of the countries of the European Union to the commercialization of GM crops in the EU, with knock-on negative effects in developing countries and also the campaigns waged by some NGOs opposed to GM technology.

The slower rate of investments by industry in mainstream GM crops has to some extent been offset by new investments in areas such as genomics and increased investments and interest by some key developing countries who view GM crops as important elements in their future strategy for food, feed and fiber security. Notable amongst the developing countries is China which made its initial investments in crop biotechnology in the mid 1980s. By 1999, there were 35 institutes in China conducting research on crop biotechnology with a staff of 1,200 plus another 800 staff at other institutions for a total of 2,000. The annual R&D budget in China for crop biotechnology in 1999 was $112 million (Huang et al 2002) with a commitment to increase it by 400% by 2005. China invests more than half of the R&D crop biotech budget of the developing countries estimated at $180 million. Other independent estimates by consultants suggest that crop biotechnology investments in China could be as high as $300 million (Kalaitzandonakes 2000). China, which conducts biotechnology research on 50 plant species and 120 functional genes, has approved 45 GM crop applications for field trials, 65 for environmental release and 31 for commercialization. These crops include the three major food staples: rice for insect resistance (Bt and CpTi) and disease resistance (Xa 21), and herbicide and salt tolerance; wheat for BYDV virus disease resistance and quality improvement; and maize for insect resistance and quality improvement. As much as 90% of GM crop applications are focused on insect and disease resistance. About 9.2% of government R&D support for crop research is devoted to biotechnology (Huang et al 2002). The positive Chinese experience with Bt cotton provides home-grown evidence that some of the perceptions of antibiotech critics are not substantiated in practice and that the technology can deliver significant agronomic, economic, environmental health and social benefits to small resource-poor farmers and contribute to the alleviation of poverty.

India is also increasing its investment in crop biotechnology in both the public and private sectors. Following approval by the Government of India to commercialize Bt cotton in 2002, it was noteworthy that the Genetic Engineering Advisory Committee (GEAC) approved field trials of GM mustard and indicated its intent to consider applications for GM soybean and maize. The Indian Council of Agricultural Research (ICAR) is committed to biotechnology and is already developing its own Bt cotton and the indigenous private sector in India is increasing its investments in GM technology. It is estimated that India is investing $15 million per year in public sector research with an additional $10 million by the private sector for a total of $25 million.

In Latin America, Brazil is investing up to $3 million per year through its national agricultural research system, EMBRAPA, and The Sao Paulo Research Foundation is investing up to $10 million, plus private sector investment of $2 million for a total of $15 million per year.

Other developing countries that are investing in crop biotechnology include Pakistan and Malaysia, Thailand, Indonesia, Philippines and Vietnam in South East Asia. In Latin America, Brazil, Mexico, Cuba, Argentina and Chile have agricultural biotech activities. In Africa, the major investments are in South Africa, Egypt, Zimbabwe, and Kenya, with the President of Nigeria having committed $263 million per year in 2001, for three years for biotechnology in agriculture and medicine.

Reviewing investments by both the private and public sectors in crop biotechnology in 2001(Table 14), the total R&D expenditure in crop biotechnology was estimated to be

Table 14. 2001 Estimates of Global R&D Expenditures on Crop Biotechnology

	$ millions	
Industrial		**4,220**
Private	3,100	
Public	1,120	
Developing Countries*		**180**
China	115*	
India	25	
Brazil	15	
Others	25	
Total		**4,400**

Source: Compiled by Clive James, based on industry and public sector estimates. Global estimate for crop biotechnology of $4.4 billion courtesy of Freedonia Group Inc., 2002 Personal Communication. Breakdown of $4.4 billion from various other sources: * 1999 estimate (Huang et al 2002); public sector investments in China could be as high as $300 million (Kalaitzandonakes 2000): global investments in crop biotechnology (Huang et al 2002, James 1997); ** Includes public (80%) and private sector (20%) expenditures.

Table 15. Global Value of Transgenic Crop Market 1996-2010

Year	Millions of $
1996	148
1997	859
1998	1,970
1999	2,947
2000	3,044
2001	3,839
2005	5,000
2010	10,000 to 15,000

Source: Wood Mackenzie estimates for 1996 to 2001, Projections by Clive James for 2005 and 2010 approximately $4.4 billion (Freedonia 2002). The industrial country investments (author estimates) comprised >95% of the total global investments at $4.22 billion, with the balance of $180 million invested by the developing countries, mainly by the public sector, with China investing the majority of the R&D resources. The success and return on investment that China has achieved with Bt cotton, which delivered total benefits of $750 million at a national level in 2001, of which at least half is attributable to the CAAS Bt cotton varieties, is an important experience that can catalyze and reinforce China's intent to quadruple its R&D investments to $450 million in crop biotechnology by 2005. Similar progress by India with Bt cotton could provide the incentive for India to accelerate and increase its investments in crop biotechnology. China and India, the two most populous countries in the world, with a combined population of 2.3 billion and 250,000,000 hectares of crop land could provide the role models and stimulus for other developing countries in Asia, Latin America, and Africa to make their own investments in crop biotechnology. The incentive for countries like China and India, two countries with a strong tradition in trading, is not only to develop GM products to meet their own food, feed and fiber needs, but also to develop new markets for their GM crops in other developing countries of the South, where the majority of the 1.5 billion hectares of crop land is cultivated, and where the need for food, feed and fiber is greatest.

Given the above status of R&D expenditures in crop biotechnology and the indications that global area of 52.6 million hectares of GM crops in 2001 will continue to grow in 2002 and beyond, the global deployment of GM crops is expected to increase to $5 billion by 2005 and up to $10 to $15 billion by 2010, (Table 15) with both agronomic and quality traits contributing to increased value. These estimates do not include the area of GM crops reported to be grown in countries such as Brazil, where official approval is still pending despite the fact that farmers have planted substantial areas of GM crops for several years.

6. OVERVIEW OF THE COMMERCIAL SEED INDUSTRY

The author estimates that, expressed as a proportion of the global commercial seed market, transgenic seed represents approximately 13% of the estimated $ 30 billion plus global commercial seed market in 2000 (FIS 2001).

Given that seed is the vehicle for incorporating and deploying transgenic traits, it is instructive to characterize the global commercial seed market to gain a sense of the scope, scale and size of the relative sub-segments of the global market classified by country, or seed, or exports. The latest estimate for the global commercial seed market is approximately $30 billion (FIS 2001), with almost 30% of the market in the developing countries. Six of the top ten country markets (Table 16) are in the industrial countries: USA ($ 5.7 billion), Japan ($ 2.5 billion), Commonwealth of Independent States ($ 2 billion), France ($ 1.4 billion), Germany ($ 1.0 billion) and Italy ($ 650 million). The four developing countries in the top ten are China ($ 3 billion), Brazil ($ 1.2 billion), Argentina ($ 930 million) and India ($900 million). Of the 13 countries that grew transgenic crops in 2000, nine are in the top twenty countries in terms of seed sales; the four exceptions are South Africa, Romania, Bulgaria and Uruguay.

Table 16. Latest Estimated Values (US $ Millions) of the Commercial Markets for Seed and Planting Material for the Top 20 Countries

Country	Internal Commercial Market
USA	5,700
China	3,000
Japan	2,500
CIS	2,000
France	1,370
Brazil	1,200
Germany	1,000
Argentina	930
India	900
Italy	650
United Kingdom	570
Canada	550
Poland	400
Mexico	350
Spain	300
Netherlands	300
Australia	280
Hungary	200
Denmark	200
Sweden	200
Total	**22,600***

* This total represents the sum of the commercial seed markets of the 20 listed countries. The commercial world seed market is assessed at US$ 30 billion.

Source: FIS, 2001.

Considering seed exports worldwide, the global market is valued at approximately $3.5 billion, equivalent to about 10% of the global market valued at $ 30 billion (Appendix Table 1A). Maize is the most important seed export market, valued at $ 530 million annually. The top five crops that have export sales of more than $ 75 million annually are maize ($ 530 million), herbage crops ($ 427 million), potato ($ 400 million), beet ($ 308 million) and wheat ($ 75 million). Breaking down the seed export market by country, out of the top ten countries the top nine are industrial countries with annual exports of seeds valued from $ 799 million to $ 105 million. Given the ongoing debate in Europe re transgenic crops, it is noteworthy that approximately half of the global seed export sales are from European countries. Out of a total global market of $3.5 billion, the USA is ranked # 1 with $ 799 million (Appendix Table 2A), followed by the Netherlands ($ 620 million), France ($ 498 million), Denmark ($190 million), Germany ($ 185 million), Chile ($144 million) Canada ($122 million), Belgium ($ 111 million), Italy ($ 111 million) and Japan ($ 105 million) for a total of $ 2.9 billion. Only one of the top ten countries exporting seeds is a developing country - Chile with annual sales of $ 144 million.

7. OVERVIEW OF DEVELOPMENTS IN THE CROP BIOTECHNOLOGY INDUSTRY

The major developments in crop biotechnology in the private sector in 2001 are summarized in Table 17. The narratives below, discuss the specific developments in each of four areas, acquisitions, mergers and spin-offs, genomics and product discovery, patents and licensing, and re-registration, approvals and commercialization.

7.1 Acquisitions, Mergers and Spin-offs

Acquisitions, alliances, mergers and spin-offs continued to impact the industry in 2001 albeit at a significantly slower pace than earlier years. Nonetheless, two significant acquisitions were completed in 2001. In February, Dow AgroSciences acquired Rohm & Haas for approximately US$ 1 billion. The agreement included Rohm & Haas' biotechnology portfolio. Rohm & Haas, with sales of approximately $ 500 million in 2000, concentrated on high value specialized markets such as fruit and vegetables rather than the major agricultural crops. Rohm and Haas enjoyed significant growth in revenues during the last decade when many of the major agrochemical companies faced a more challenging situation. Reconfigured agrochemical revenue for Dow AgroSciences and Rohm & Haas in 2000 was $ 2.6 billion, making Dow AgroSciences the fifth largest agchemical company on a global basis with 9 % of the sales.

A more significant acquisition took place in September 2001 when Bayer confirmed the acquisition of Aventis Crop Science for $6.6 billion, approximately 1.8 times 2000 sales. With the acquisition of Aventis, Bayer becomes the second largest agrochemical company to Syngenta with reconfigured sales of $ 5.8 billion for 2000. The new entity, Bayer Crop Science, will be headquartered in Monheim, Germany. The acquisition does not include Starlink.

Monsanto acquired Limagrain Canada Seeds in Saskatchewan with activities in R&D, production and marketing. Monsanto acquired a minority share in 1997 with an option to increase its share at a future date. Pharmacia announced that it would spin off Monsanto in the second half of 2002. The spin off of Pharmacia's 85.3 % share in Monsanto will allow the two businesses to operate separately. Acquisition of Monsanto by one of the leading agbiochemical companies is not thought to be likely because of antitrust considerations. Syngenta acquired the remaining 44 % of its shares in the joint venture with the French cereal breeding company CC Benoist, which specializes in developing wheat and barley using new technologies. Syngenta also acquired Tomono Agrica in Japan which has $ 105 million annual sales in crop protection.The Japanese companies Tomen Corporation and Nichimen Corporation merged their respective life sciences divisions into a new company.

7.2 Genomics and Product Discovery

The Torrey Mesa Research Institute (Syngenta's Genomic facility) and Myriad Genetics, in conjunction with Clemson University completed (99.5%) sequencing of the rice genome. The genome comprises 430 million DNA bases equivalent to 50,000 genes. Rice is the first crop of economic importance to be decoded after *Arabidopsis* was completed during the latter part of 2000. Syngenta will make the genomic information available to academia through collaborative arrangements and provide the information and the technology with no royalties for uses in products used by subsistence farmers. An analysis of the gene expression and rice proteins is now underway. The complete sequencing of the rice genome by Syngenta/ Myriad/Clemson follows release of a working draft by Monsanto in April 2000. The complete sequencing of the rice genome is an important step because it is the first major crop to be sequenced and has implications for other major crops.

Maxygen, the US genomics company delivered two candidate products to Syngenta, under the terms of an agreement between Maxygen and Zeneca initiated in 1999. The products represent a portfolio of improved traits for pest and disease control as well as those that confer quality, nutritional and productivity improvements. Syngenta and Egea Biosciences agreed to develop pest resistant plants that rely on naturally occurring molecules. Egea will create and synthesize long DNA chains of 30,000 bases or more, which encode for Syngenta-discovered genes from natural sources.

The US biotechnology company, Exelixis reported that its joint venture company with Bayer, Genoptera had developed several novel insecticide targets for assessment by Bayer, which has exclusive rights on the products. Bayer extended another contract with the US genomics company Paradigm Genetics for another 5 years at a cost of $ 30 million to discover new herbicides. Paradigm Genetics, developed a DNA micro array for the fungal causal agent of the economically important disease rice blast. The micro array allows analysis of the fungal pathogen's gene expression. Paradigm Genetics reported progress in its collaboration with Monsanto in the use of its Gene Function Factory technology to discover the function of genes. The agreement has been extended for a six year period and the scope of work broadened. In May 2000 the Monsanto/Paradigm Genetics collaboration was extended to include Renessen, the joint venture between Monsanto and Cargill focusing on quality traits in processed grains and oil seeds. Paradigm Genetics was granted a US patent for a gene that can be used as a herbicide target.

Dow Chemical, Epicyte Pharmaceuticals and Centocor agreed to collaborate to evaluate human monoclonal antibody production in plants. Dow will utilize its gene expression expertise and maize production and processing expertise in conjunction with Epicyte's Plantibody technology to produce the Centecor antibody. Dow claims that the technique is more cost effective than current technologies and can be used for high volume production.

Dow AgroSciences terminated its collaboration between its subsidiary, Mycogen, and Demegen. The work was initiated in 1997 to develop disease resistant and nutritionally enhanced crops. Dow AgroSciences and Exelixis announced that the latter has delivered four crop protection targets related to weed and disease control. DuPont and the US company Discovery Partners International agreed to collaborate in the discovery and development of products for DuPont's Crop Protection Division. Monsanto and the US genomic company Mendel agreed to a five year $ 20 million R&D contract, which extends their first collaboration initiated in 1997. The project focuses on the identification by Mendel of genes for improved yield, drought and disease resistance.

7.3 Patents and Licensing

Delta and Pine Land (D & PL) obtained exclusive rights from USDA (ARS) for the commercialization of a pollen transformation system in a broad range of crops. D & PL plans to sublicense the technology which is less complicated and costly than current transformation technology in that it does not require regeneration of plants from transformed cells. The technique involves only transfer of pollen which is then used directly to pollinate the target plant. D & PL hope that the technology will facilitate and accelerate the development of transgenic crops in cereals, legumes, forages, citrus, fruits and vegetables.

The European Patent Office reconfirmed the legality of Aventis' patent (EP 275957) for GM plants tolerant to Glufosinate (Liberty) which had been challenged by Greenpeace. The patent was granted to Aventis on the basis that the gene, isolated from a bacterium had been modified prior to patenting and was not the natural gene found in wild populations, as claimed by Greenpeace. The gene is deployed by Aventis in both maize and canola. MPB Cologne from Germany licensed its "gene switch" technology to Aventis Crop Science. The technology allows activation or deactivation of a specific gene and is used to excise DNA sequences from transgenic crops.

Neogen Corporation and Envirologix Inc signed non-exclusive licenses with Monsanto to acquire proprietary technology for the detection of the glyphosate trait in soybean, cotton, canola and corn and specific Bt traits in corn and cotton. Renessen (the joint venture between Cargill and Monsanto) agreed to a world wide licensing agreement with Sangamo Sciences, USA, to utilize gene regulation technology for improving selected crops for animal feed and processing. Dow AgroSciences licensed Third Wave Agbio's technology to detect single nucleotide polymorphics (SNP) and DNA sequences in genetically engineered plants before commercialization; it can be used for elimination of antibiotic markers. SemiBioSys, a Canadian biotech company, was granted a US patent on plant-based somatropin production. SemiBioSys uses GM technology to express proteins in safflower seed which facilitates the extraction of oil. SemiBioSys has a collaborative agreement with Syngenta to develop technology featuring transgenic expression of proteins in oil seeds.

7.4 Reregistration, Approvals and Commercialization

EPA renewed Monsanto's Bollgard® cotton for another 5 years in the US, noting that there is no evidence of the development of insects resistant to Bt. Over a six year period Monsanto data indicated an average yield increase of 7 % for Bt compared with unprotected cotton and an annual saving of 2 million pounds (0.9 million kg) of insecticide in the US since the introduction of its Bt cotton. In the US, EPA re-registered Bt maize for 7 years, terminating on 16 October 2008. EPA noted that the scientific data indicated that Bt maize does not pose a risk to human health and the environment, decreases use of pesticides and does not impact on Monarch butterflies. Companies with Bt maize registration include Monsanto, Syngenta, Pioneer/DuPont and Mycogen/Dow AgroSciences.

South Africa introduced its fourth GM crop, Monsanto's RR soybean, which compliments the other 3 GM crops already commercialized - Bt yellow maize for feed, Bt cotton and RR cotton.

Pioneer and Dow AgroSciences announced that a new Bt maize, Herculex 1 had been approved for food and feed use in the US. Herculex 1 contains the Cry F1 gene that provides broader resistance to pests including European corn borer, Southwestern corn borer, black cutworm, fall armyworm, and intermediate resistance to corn earworm. Dow AgroSciences will develop its Nexera canolas for BASF's Clearfield Production System. The improved varieties will be tolerant to imidazolinone herbicides and contain the Natreon quality oils which have higher oxidative stability and reduced trans-fat content.

Monsanto obtained commercial approval for RR cotton in Argentina. The approval was granted by the Ministry of Agriculture following review of the submission by CONABIA and SENASA. A modest launch of RR cotton was planned for 2001. Monsanto plans to discontinue sale of New Leaf Potato after the 2001 season. In 1999 Naturemark deployed New Leaf varieties with stacked traits; New Leaf Y resistant to Colorado beetle and virus Y and New Leaf Plus (resistant to Colorado beetle and leaf roll virus). In both cases the Bt gene Cry 3Aa was used to effectively confer resistance to Colorado beetle which is a major insect pest in North America. The major issue contributing to the decision was the refusal of potato processors to accept GM crops despite the fact that New Leaf potatoes required significantly less insecticides, which ironically is assigned high priority by the public at large. Monsanto plans to reintroduce New Leaf potatoes in appropriate markets in the future. Monsanto recalled Quest RR canola (Event GT 73) in Canada because some seed lots had trace amounts of another event, GT 200. Whereas both events have been approved in Canada, GT 200 has not yet been approved in some Canadian export markets. Monsanto's offer was made in line with its quality assurance program for RR canola. Monsanto inaugurated a cotton molecular breeding facility in Mississippi and an upgraded maize seed facility in Nebraska. Monsanto announced that a simplified pricing system would be used for GM soybean and maize from 2002 onwards. The current technology fee, payable by farmers directly to Monsanto, is being replaced by a royalty fee payable by the seed companies to Monsanto. Thus, farmers will only make a single payment for the seed which will include the royalty fee. The new pricing system will not apply to Monsanto's GM cotton and canola.

BASF Plant Science established a subsidiary in the US to develop maize inbred lines. The new company will work with established US seed companies with well-adapted germplasm which is recognized to be a significant advantage. BASF's US based plant biotech company ExSeed Genetics, inaugurated an R&D facility in Iowa, USA, to conduct strategic research on traits that confer nutritionally enhanced maize.

Syngenta and the Australian National Wheat Exports Board (AWB) announced an alliance to develop improved wheat varieties. The alliance is intended to be the first step in establishing a joint venture to commercialize new wheat varieties in Australia. Syngenta will reduce the number of its global technology centers from 12 to 6; the closures, along with the closing of 10 manufacturing plants will result in $ 150 million savings by 2004. A New Technology Segment in the Syngenta reporting structure will monitor R&D costs for product development including genomics. The 6 new portfolio groups are: marker assisted breeding, input traits, agronomic effects, animal feed, functional foods and consumer health. With the restructuring, Syngenta's R&D investments are $ 161 million in New Technology, $ 111 million in seeds development, and $ 473 million in agrochemicals. Syngenta, which spent 10.4% of its 2000 revenue of $ 7.17 billion on R&D, plans to reduce its R&D expenditures below 10% of revenues. Syngenta closed its Mogen R&D facility in the Netherlands. The discontinuation of Mogen activities was due to a duplication of effort which came about following the formation of Syngenta in November 2000. Aventis Crop Science and AVEBE in Germany agreed to form a joint venture company called Solavista to conduct R&D on potato starch. Potatoes with improved starch will be developed for industrial use in paper production, textiles, glues and processed foods.

For the convenience and information of readers, the highlights in the crop biotechnology industry in 2001 are chronicled by month in Table 17.

Table 17. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
January	**Renessen** (the joint venture between **Cargill** and **Monsanto**) agreed to a world wide licensing agreement with **Sangamo Sciences**, USA, to utilize gene regulation technology for improving selected crops for animal feed and processing.
January	The Japanese companies **Tomen Corporation** and **Nichimen Corporation** agreed to merge their respective life sciences divisions into a new company.
January	The **Torrey Mesa Research Institute** (**Syngenta**'s Genomic facility) and **Myriad Genetics**, in conjunction with **Clemson University** announced the completion (99.5 %) of the sequencing of the rice genome.
February	**Dow AgroSciences** agrees to acquire **Rohm & Haas** for approximately US$ 1 billion. The agreement includes Rohm & Haas biotechnology portfolio.
February	**Delta and Pine Land (D & PL)** obtains exclusive rights from **USDA** (ARS) for the commercialization of a pollen transformation system in a broad range of crops.
February	European Patent Office reconfirms the legality of **Aventis**' patent (EP 275957) for GM plants tolerant to Glufosinate (Liberty) which had been challenged by **Greenpeace**.
March	**Monsanto** plans to discontinue sale of New Leaf Potato after the 2001 season. In 1999 **Naturemark** deployed New Leaf varieties with stacked traits; New Leaf Y resistant to Colorado beetle and virus Y and New Leaf Plus (resistant to Colorado beetle and leaf roll virus).
March	**Monsanto** and **Aventis** settle two outstanding law suits on GM cotton. Monsanto authorized Aventis to commercialize RR & Bollgard® (Bt) in Aventis' FiberMax cotton varieties (developed by CSIRO Australia) in the US. Aventis authorized Monsanto to use specific Bt genes in stacked genes for multiple insect resistance.
March	A US court ruled that **Pioneer Hi-Bred International**'s license to sell **Monsanto** RR soybeans and canola was terminated when Pioneer merged with **DuPont** in October 1999. However, the same court also ruled that Monsanto was not entitled to damages. Pioneer plans to appeal the decision and to continue marketing the products in the meantime.

continued...

Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
March	The US biotechnology company, **Exelixis** reported that its joint venture company with **Bayer**, **Genoptera** had developed several novel insecticide targets for assessment by Bayer, which has exclusive rights on the products.
April	**Neogen Corporation** and **Envirologix Inc** sign non-exclusive licenses with Monsanto to acquire proprietary technology for the detection of glyphosate trait in soybean, cotton, canola and corn and specific Bt traits in corn and cotton.
April	**Monsanto** recalls Quest RR canola (Event GT 73) in Canada because some seed lots had trace amounts of another event, GT 200. Whereas both events have been approved in Canada, GT 200 has not yet been approved in some Canadian export markets. Monsanto's offer was made in line with its quality assurance program for RR canola.
May	**Monsanto** obtains commercial approval for RR cotton in Argentina. The approval was granted by the Ministry of Agriculture following review of the submission by CONABIA and SENASA. A modest launch of RR cotton is planned for 2001.
June	**Bayer** is emerging as the most likely candidate to acquire **Aventis**' crop protection business. Bayer is the fifth largest agchemical company globally with revenue of $2.3 billion in 2000. Bayer and Aventis combined revenue in 2000 would have been $ 5.8 billion, second only to Syngenta at $ 6.2 billion. Bayer, which is currently not active in crop biotechnology would acquire a GM crop portfolio of herbicide tolerant and insect resistant crops if it acquires Aventis.
June	**Monsanto** acquires **Limagrain Canada Seeds** in Saskatchewan with activities in R&D, production and marketing. Monsanto acquired a minority share in 1997 with an option to increase its share at a future date.
June	**Dow AgroSciences** completes acquisition of **Rohm & Haas**. In addition to business in North America, the deal includes businesses in Brazil, Colombia, China, France and Italy.
June	The **Global Crop Protection Federation** changes its name to **Croplife International**, whose members represent 90 % of the global market for crop protection.

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
June	**Monsanto** announces that a simplified pricing system will be used for GM soybean and maize from 2002 onwards. The current technology fee, payable by farmers directly to Monsanto, will be replaced by a royalty fee payable by the seed companies to Monsanto. Thus, farmers will only make a single payment for the seed which will include the royalty fee. The new pricing system will not apply to Monsanto's GM cotton and canola.
June	**Bayer** extends contract with **Paradigm Genetics (US)** for another 5 years at a cost of $ 30 million to discover new herbicides.
June	**Pioneer** and **Dow AgroSciences** announce that a new Bt maize, Herculex 1 has been approved for food and feed use in the US. Herculex 1 contains the Cry F1a gene that provides broader resistance to the pests European corn borer, Southwestern corn borer, black cutworm, fall armyworm, and intermediate resistance to corn earworm.
July	**Syngenta** acquires **Tomono Agrica** in Japan which has $ 105 million annual sales in crop protection.
July	**BASF Plant Science** establishes a subsidiary in the US to develop maize inbred lines. The new company will work with established US seed companies with well-adapted germplasm which is recognized to be a significant advantage.
July	**Syngenta** and the **Australian National Wheat Exports Board (AWB)** announces an alliance to develop improved wheat varieties. The alliance is intended to be the first step in establishing a joint venture to commercialize new wheat varieties in Australia.
July	EPA in the US did not accede to the **Aventis** request to establish a 20 parts per billion tolerance for the Cry 9c protein in Starlink maize. However EPA also stressed that the risk of exposure that would induce an allergic response is low.
August	**Syngenta** will reduce the number of its global technology centers from 12 to 6; the closures, along with the closing of 10 manufacturing plants will result in $ 150 million savings by 2004. A New Technology Segment in the Syngenta reporting structure will monitor R&D costs for product development including genomics. The 6 new portfolio

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
	structure will monitor R&D costs for product development including genomics. The 6 new portfolio groups are: marker assisted breeding, input traits, agronomic effects, animal feed, functional foods and consumer health. With the restructuring, Syngenta's R&D investments are $ 161 million in New Technology, $ 111 million in seeds development, and $ 473 million in agrochemicals.
August	**Pioneer** inaugurates a new $ 10 million soybean production facility in Illinois. Pioneer's market share for soybean in North America is estimated at approximately 24 %.
August	**BASF**'s US based plant biotech company **ExSeed Genetics**, inaugurates R&D facility in Iowa, USA, to conduct strategic research on traits that confer nutritionally enhanced maize.
August	**Dow AgroSciences** licenses **Third Wave Agbio**'s technology to detect single nucleotide polymorphics (SNP) and DNA sequences in genetically engineered plants.
August	**MPB Cologne** from Germany licenses its "gene switch" technology to **Aventis Crop Science**. The technology allows activation or deactivation of a specific gene. The technology excises DNA sequences from transgenic crops before commercialization, and is used for elimination of antibiotic markers.
August	**Monsanto** inaugurates a cotton molecular breeding facility in Mississippi and an upgraded maize seed facility in Nebraska.
August	The US genomic company, **Paradigm**, develops a DNA micro array for the fungus which causes rice blast. The micro array allows the analysis of the fungal pathogen's gene expression.
September	**Aventis** and **CropScience Shinogi**, Tokyo, establish a joint venture headquartered in Japan.
September	On 20 September **Bayer** confirms the acquisition of **Aventis Crop Science** for $ 6.6 billion, approximately 1.8 times 2000 sales. With the acquisition of Aventis, Bayer became the second largest agrochemical company to Syngenta ($6.2 billion) with reconfigured sales of $ 5.8 billion in 2000. The new entity Bayer Crop Science will be headquartered in Monheim, Germany. The acquisition does not include Starlink.

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
September	**Dow Chemical**, **Epicyte Pharmaceuticals** and **Centocor** agree to collaborate to evaluate human monoclonal antibody production in plants. Dow will utilize its gene expression expertise and maize production and processing in conjunction with Epicyte's Plantibody technology to produce the Centecor antibody. Dow claims that the technique is more cost effective than current technologies and can be used for high volume production.
September	EPA renews **Monsanto**'s Bollgard® cotton for another 5 years in the US, noting that there is no evidence of the development of insects resistant to Bt. Over a six year period Monsanto data indicated an average yield increase of 7 % for Bt compared with unprotected cotton and an annual saving of 2 million pounds (0.9 million kg) of insecticide in the US since the introduction of its Bt cotton in 1996.
September	The US biotechnology company **Paradigm Genetics** reports progress in its collaboration with **Monsanto** in the use of its Gene Function Factory technology to discover the function of genes. The agreement has been extended for a six year period and the scope of work broadened. In May 2000 the collaboration was extended to include **Renessen**, the joint venture between **Monsanto** and **Cargill** focusing on quality traits in processed grains and oil seeds.
September	**Dow Chemical** was awarded a $ 5 million grant by the US Department of Energy to research production of plastics and chemicals from renewable plant oils such as castor oil. The aim of the project is to assess the feasibility of substituting non-renewable petrochemical materials; the project is part of a $ 30 million US Dept. of Energy initiative to develop bioenergy products.
October	**Monsanto** and **DuPont** resolve issues related to the use of the MON 810 Bt event in maize marketed as Yield Gard. **Monsanto** and **Dow Agro Sciences** also resolved issues related to the use of Bt maize technology by Dow AgroSciences acquired from **Mycogen**, and with implications for the new Bt maize Herculex 1.
October	**Syngenta** acquires the remaining 44 % of its shares with the joint venture with the French cereal breeding company **CC Benoist**, which specializes in developing wheat and barley using new technologies.

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
October	In the US, EPA re-registers Bt maize for 7 years, terminating on 16 October 2008. EPA noted the scientific data indicated that Bt maize does not pose a risk to human health and the environment, decreases use of pesticides and does not impact on Monarch butterflies. Companies with Bt maize registration include **Monsanto**, **Syngenta**, **Pioneer**/**DuPont** and **Mycogen**/**Dow AgroSciences**.
October	The US biotechnology company **Paradigm Genetics** is granted a US patent for a gene that can be used a herbicide target.
October	**SemiBioSys**, a Canadian biotech company, is granted a US patent on plant-based somatropin production. SemiBioSys uses GM technology to express proteins in safflower seed which facilitates the extraction of oil. SemiBioSys has a collaborative agreement with **Syngenta** to develop technology featuring transgenic expression of proteins in oil seeds.
November	**Pharmacia** announces that it will spin off **Monsanto** in the second half of 2002. The spin off of its 85.3 % share in Monsanto will allow the two businesses to operate separately. Acquisition of Monsanto by one of the leading agbiochemical companies is not thought to be likely because of antitrust considerations.
November	**Monsanto** and the US genomic company **Mendel** agree to a five year $ 20 million R&D contract, which extends the first collaboration initiated in 1997. The project focuses on the identification by Mendel of genes for improved yield , drought and disease resistance.
November	**Aventis Crop Science** and **AVEBE** in Germany agree to form a joint venture company called **Solavista** to conduct R&D on potato starch. Potatoes with improved starch will be developed for use in industrial use in paper production, textiles, glues and processed foods.
November	**Maxygen**, the US genomics company delivers two candidate products to **Syngenta**, under the terms of an agreement between Maxygen and Zeneca initiated in 1999. The products represent a portfolio of improved traits for pest and disease control as well as those that confer quality, nutritional and productivity improvements.

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
November	**Syngenta** and **Egea Biosciences** agree to develop pest resistant plants that rely on naturally occurring molecules. Egea will create and synthesize long DNA chains of 30,000 bases or more, which encode for Syngenta-discovered genes from natural sources.
November	**Dow AgroSciences** terminates collaboration between **Mycogen**, its subsidiary, and **Demegen**. The work was initiated in 1997 to develop disease resistant and nutritionally enhanced crops.
November	**DuPont** and the US company **Discovery Partners International** agree to collaborate in the discovery and development of products for DuPont's Crop Protection Division.
November	**Dow AgroSciences** and **Exelixis** announce that the latter has delivered four crop protection targets related to weed and disease control.
December	**Dow AgroSciences** will develop its Nexera canolas for **BASF**'s Clearfield Production System. The improved varieties will be tolerant to imidazolinone herbicides and contain the Natreon quality oils which have higher oxidative stability and reduced trans-fat content.
December	South Africa introduces its fourth GM crop, **Monsanto**'s RR soybean which compliments the other 3 GM crops already commercialized - BT yellow maize for feed, Bt cotton and RR cotton.
December	**Syngenta** closes the Mogen R&D facility in the Netherlands. The discontinuation of Mogen activities is associated with a duplication of effort following the formation of Syngenta in November 2000.
December	**Syngenta**, which spent 10.4 % of its 2000 revenue of $ 7.17 billion on R&D, plans to reduce its R&D expenditures below 10 %.

Source: Compiled by Clive James (2002) from various sources, including Wood MacKenzie.

8. ECONOMIC BENEFITS OF GM CROPS

In the 2000 ISAAA Global Review of Transgenic Crops (James 2001a), an assessment was published of the global benefits associated with the principal GM crops, soybean, corn, cotton and canola. In the interim, several studies and surveys have been conducted and these are summarized here to provide the reader with the current information on benefits from GM crops.

8.1. Economic Benefits of GM Crops in the USA

The economic benefits in the US have recently been assessed and updated (Gianessi et al 2002) and are summarized here. The work reported by Gianessi et al is particularly useful because improved and uniform methodology has been used to assess all the principal GM crops in the US, making comparisons between crops more meaningful. The study examined current benefits for 2001 as well as potential future benefits. Forty case studies for GM crops are usefully and critically compared with previous assessments by the same authors as well as comparisons with estimates published by other authors. The study (Gianessi et al 2002) reports results for a typical year for the three categories of crops, detailed below:

8.1.1 Benefits from the 8 GM crop varieties planted commercially in the US in 2001

The total economic benefit to US farmers who planted GM crops on a total area of

Table 18. Impact of GM Crops Planted in USA in 2001

GM Crop/Trait	Ha 000s	Production Millions		Pesticide Use Millions		Net Economic Gain	
		Lbs.	(Kgs.)	Lbs.	(Kgs.)	National $ Millions	Farm level $/Ha
1. Soybean HT	20,241	-		-28.7	(-13.0)	1,011	50
2. Cotton HT	3,764	-		-6.2	(-2.8)	133	35
3. Corn IR	6,041	+3,541	(+1,606)	-2.6	(-1.2)	125	21
4. Cotton IR	2,082	+185	(+84)	-1.9	(-0.9)	103	50
5. Corn HT	2,350	-		-5.8	(-2.6)	58	25
6. Canola HT	352	-		-0.5	(-0.2)	11	31
7. Papaya VR	<1	+53	(+24)	-		17	2,625
8. Squash VR	<2	+6	(+3)	-		1	803
Total	**34,831**	**+3,875**	**(+1,717)**	**-45.7**	**(-20.7)**	**1,459**	**Avg 42**

Source: Gianessi et al., 2002. HT - Herbicide Tolerant, IR - Insect Resistant, VR - Virus Resistant approximately 35 million hectares in 2001 was estimated at $ 1.5 billion (Table 18). This is equivalent to an overall national economic gain for farmers of $ 42 per hectare compared with corresponding conventional varieties. The economic benefits were due to various factors including higher yields, lower costs of production, decreased use and/or lower cost of pesticides, less need for cultivation and pesticide spraying.

Of the 8 commercial GM crops planted in the US in 2001, 4 delivered benefits to farmers in excess of $ 100 million. Approximately two-thirds, equivalent to $ 1 billion, of the total benefits were associated with one crop, RR soybean, planted on over 20 million hectares; the economic gain per hectare for RR soybean was $ 50, compared with a corresponding conventional variety. The second largest benefit of $ 133 million, equivalent to $ 35 per hectare was for herbicide tolerant cotton, planted on 3.7 million hectares. The third ranking at $ 125 million and equivalent to $21 per hectare, was for Bt corn grown on 6 million hectares, and the fourth crop was Bt cotton, planted on 2 million hectares, which delivered a national benefit of $ 103 million, equivalent to $ 50 per hectare – the same return as RR soybean. Four other GM crops also benefited farmers with significant economic benefits at below $ 100 million per crop at a national level. The four crops were herbicide tolerant corn, grown on 2.4 million hectares which delivered benefits of $ 58 million to US farmers in 2001, equivalent to $ 25 per hectare; herbicide tolerant canola grown on 352,000 hectares resulted in an economic gain to farmers of $ 11 million nationally, and equivalent to $ 31 per hectare; virus resistant papaya grown on less than 1,000 hectares resulted in a benefit to farmers in Hawaii of $17 million, equivalent to $ 2,625 per hectare; and virus resistant squash grown on less than 2,000 hectares delivered a benefit of $ 1 million, equivalent to approximately $ 800 per hectare.

One of the factors that resulted in significant economic savings was the lower cost of crop protection due to a decreased need for pesticides. In the US in 2001, savings of 45.7 million pounds or 20.7 million kg (20,700 metric tons) of pesticide (active ingredient or a.i.) were realized due to the adoption of 6 herbicide tolerant and insect resistant crops requiring less pesticides. Most savings were made on RR soybean, which required 28.7 million pounds or 13.0 million kg less herbicide (active ingredient). Similarly, herbicide tolerant cotton required 6.2 million pounds/2.8 million kg less herbicide (a.i.); herbicide resistant corn required 5.8 million pounds/2.6 million kg less insecticide (a.i.); insect resistant corn required 2.6 million pounds/1.2 million kg less insecticide (a.i.); insect resistant cotton consumed 1.9 million pounds/0.9 million kg less insecticide (a.i.); and finally herbicide tolerant canola consumed 0.5 million pounds/0.2 million kg less herbicide (a.i.).

In addition to pesticide savings, yield increases in 2001 resulted from the deployment of some GM crops in the US. The largest increase was for insect resistant corn, which produced 3.5

billion pounds/1.6 billion kg for Bt corn farmers in the US in 2001.The deployment of Bt cotton resulted in an increase in production of 185 million pounds/84 million kg, virus resistant papaya in an increased production of 53 million pounds/24million kg, and virus resistant squash resulted in a production gain of 6 million pounds or almost 3 million kg.

8.1.2 Potential impact of GM crops approved but not deployed in US in 2001

The study by Gianessi et al (2002) includes four case studies of GM crops where the GM product is approved but pending deployment; potential benefits were calculated using the same methodology. In a typical year the expected overall economic gain for US farmers when they deploy all four crops, HT sugar beet, IR/VR potato, IR sweet corn and HT sweet corn is projected at $158 million, with an associated 1 billion pound increase in production and a savings of 583,000 pounds of insecticides and herbicides; see details in Table 19. Of the total national economic gain of $158 million, $93 million equivalent to $153 gain per hectare) was attributed to herbicide tolerant sugar beet grown on 600,000 hectares with an addition of 963,000 pounds/437,000 kg of herbicide (a.i.). An economic gain of $59 million (equivalent to $233 gain per hectare) is projected for insect/virus resistant potatoes grown on 250,000 hectares with a savings of 1.45 million pounds/657,000 kg of insecticide (a.i). Potential gains from Bt and herbicide tolerant sweet corn grown only on 25,000 hectares are, as expected, modest at $5 million and $ 1million respectively.

Table 19. Potential Impact of GM Crops Approved but not Adopted in USA in 2001

Crop/Trait	000s acres (has.)	Economic Benefit Total $ millions	Gain $/ha	Pesticide Use lbs 000s	(kg)
Sugar beet HT	1,500 (607)	93	153	+963	(+437)
Potato IR/VR	621 (251)	59	233	-1,450	(-657)
Sweet corn IR	32 (13)	5	433	-112	(-51)
Sweet corn HT	30 (12)	1	83	+16	(+7)
Total	**2,183 (882)**	**158**		**-583**	**(-264)**

Source: Gianessi et al., 2002. HT - Herbicide Tolerant, IR - Insect Resistant, VR - Virus Resistant

8.1.3 Potential impact of GM crops in the USA that are under development for current and longer-term constraints

The potential economic impact for 32 GM crop products involving 19 crops have been projected by Gianessi et al (2002). For a typical year, the total projected economic benefit for the 32 products is estimated at $853 million with an increased production of about 10 billion pounds/4.3 billion kg (a.i.).

The data in Table 20 summarizes the economic and production gains and pesticide savings reviewed above.

- Firstly, US farmers who planted 35 million hectares of GM soybean, corn, cotton, canola, papaya and squash in 2001 are estimated to have made an economic gain of $ 1.5 billion, increased production by about 4 billion pounds/1.8 billion kg with pesticides savings equivalent to 46 million pounds/21 million kg (a.i.)

- Secondly, expected gains were projected for the GM crops sugar beet, potato and sweet corn that have been approved in the US but not yet deployed. For a typical year, economic gains are projected at $ 158 million 1 billion pounds/453 million kg of increased production and savings of 0.6 million pounds/0.27 million kg of pesticide (a.i).

- Thirdly, potential gains for US farmers were projected for 32 GM products comprising approximately 28 crops featuring GM applications that are at the R&D stage and not approved. For a typical year the gains projected for

Table 20. Summary of Current and Potential Gains for GM Crops in USA, 2001

Product Category	Economic Gain $ Millions	Production Gain Lbs. Millions (Kgs.)		Pesticide Savings Lbs. Millions (Kgs.)	
1. 35 million ha GM crops planted in 2001	1,459	3,785	(1,717)	46	(21)
2. GM crops, approved but not deployed	158	1,094	(496)	<1	(<1)
3. GM crops in R&D current & longer-term constraints	853	9,616	(4,362)	116	(53)
TOTAL	**2,470**	**14,495**	**(6,531)**	**162**	**(73)**

Source: Gianessi et al., 2002, modified.

these crops are $ 853 in economic value, 10 billion pounds/4.5 billion kg of production and 116 million pounds/ 53 million kg less pesticides (a.i.).

- Taking the above assessment of Gianessi et al (2002) into account, the value to US farmers in 2001 could be increased from $ 1.5 billion to $ 2.5 billion with the addition of new products that have been approved but not yet deployed, and products in the R&D phase. Similarly, potential increases in crop production could be increased from the 4 billion pounds production gain (1.8 billion kg) in 2001 to over 14 billion pounds (6.4 billion kg) in future. Finally, current pesticide savings of 46 million pounds (21 million kg) in 2001 could be increased to more than 150 million pounds (68 million kg) with the commercialization of new products. Thus, the potential market for the US, based on products that are already commercialized or under development can deliver economic benefits to farmers valued at $ 2.5 billion, increased production of over 14 billion pounds (6.4 billion kg) and pesticide savings of 162 million pounds/73 million kg (a.i.). These substantial direct benefits to farmers from GM crops in the US do not include the indirect economic, environmental and social benefits to society at large, some of which are intangible but deemed important by the public at large.

8.2 Economic Benefits from RR Soybeans in Argentina, 2001

After the USA, Argentina has the second largest area of herbicide tolerant RR soybean hectarage in the world – over 11.2 million hectares out of a total area of 12 million hectares in 2002. A detailed survey conducted by Qaim and Traxler (2002) indicated a gross margin of approximately $23 per hectare or 10% in favor of RR soybean over conventional varieties. A surplus of $303 million (90%) accrued to Argentinean soybean farmers, $28 million to the technology developers (8%) and the balance of $4 million (2%) for the consumer. The adoption of RR soybean in Argentina has, through substituting the use of less toxic classes of herbicides and low tillage practices, resulted in a positive impact on the environment.

On a global scale, the authors (Qaim and Traxler 2002) estimate that over the five year period (1996 to 2001) RR soybeans globally have generated a surplus of $1.2 billion. The largest share has accrued to consumers, $652 million (53%), followed by the technology developers, $421 million or 34%, and agricultural producers, $158 million (13%).

8.3 Benefits from Bt Corn in the Philippines

In 1999 the National Committee on Biosafety of the Philippines approved the first transgenic crop field trial with Bt corn at a single location in General Santos. In 2001 Bt corn field trials were conducted at three different locations: Isabela (3), Bukidnon (1) and Camarines Sur (1). Average farm sizes were small and ranged from 1.1 to 1.9 hectares. The objective of the multilocational study was to conduct a socio-economic assessment of the performance of Bt corn, compared with conventional corn. Four different comparisons were made for yield increases, production costs, net profitability, and the subsistence level carrying capacity of corn production; the latter is defined as whether the net income from corn production could meet the cost of purchasing a daily food basket of 2,000 kilo calories per person for a farm family of five. For cost comparisons, price of Bt corn seed was assumed to be the same as the cost of conventional seed, 2,000 pesos/bag plus 800 pesos/hectare for insecticide for a total of 2,800 pesos, compared with 2,000 pesos/bag for conventional seed. Comparisons of Bt corn field-trial results were also made with best farmer practices using field yields from a group of farmers with high yields and another with low yields.

The results (Gonzalez 2002) showed that Bt corn hybrids consistently outyielded conventional corn hybrids by 41% in trials and by 60% compared with farmer practice. Cost of production of Bt corn was 24% lower than conventional corn in field trials and 13% better than farmer practice for the group of farmers with high yields, and 39% better than farmer practice for the group of farmers with low yields. The results of the comparisons re the subsistence level carrying capacity of the technology showed that whereas Bt corn could meet the subsistence requirement of a family of five, conventional corn could not. Thus, in summary, Bt corn hybrids consistently performed better than their corresponding conventional corn hybrids, in terms of yield, production cost, profitability and in terms of capacity to meet subsistence needs of farm families. Based on this experience with Bt corn in these multilocational field trials, subsistence corn farmers in the Philippines expressed their interest and willingness to adopt Bt corn because of the higher yields and less requirements for insecticide.

8.4 Ex-Ante Study on Potential Benefits of Golden Rice in the Philippines

Vitamin A deficiency (VAD) is of significant concern in the developing world as it causes blindness in half a million children annually. Women and children suffer the most serious consequences from VAD and the poor are generally at risk because they are malnourished. Several initiatives, including the provision of vitamin supplements, food fortification and educational campaigns are currently underway to address VAD. Enhancing the precursor of Vitamin A, beta carotene through crop breeding offers a complimentary strategy and is being pursued in crops such as maize and sweet potato. However, this strategy cannot be applied to rice because beta carotene is not found in the rice endosperm. With the application of GM technology, Golden Rice has been developed with beta carotene in the endosperm (Beyer et al 2002) and an international R&D program is underway to develop well-adapted varieties of rice with adequate levels of beta carotene.

A recent *ex-ante* study (Zimmermann and Qaim 2002) analyzed the potential benefits of Golden Rice in the Philippines where VAD is a major concern. This study is of seminal importance in that it is one of the first *ex-ante* studies to assess the nutritional and health benefits from second generation GM products with quality traits that improve the nutrition of crop products, more specifically vitamin enriched products.

Acknowledging that Golden Rice alone is not a solution to VAD, the study notes that it does offer an important complementary approach to other initiatives such as supplements. For example, Golden Rice is particularly suited for deployment in rural communities. The study reaffirms that Golden Rice is currently an R&D initiative. Achieving effective conversion and adequate levels of vitamin A continue to be challenges as well as gaining producer and consumer acceptance and adequate control of poor harvest losses. The study reported that the annual health cost in the Philippines related to VAD is of the order of 0.5% of GNP, equivalent to $432 million and that Golden Rice has the potential to contribute to the reduction of this cost. Two scenarios are depicted, an optimistic and a more conservative scenario. The conservative scenario suggests that Golden Rice has the potential to reduce the number of cases of blindness by 1,514 and decrease the number of deaths by 152 annually. The more optimistic scenario projects a reduction of 8,738 cases suffering from blindness and the saving of 941 lives each year. The conservative scenario translates to savings of $23 million annually compared with $137 million for the more optimistic scenario. Preliminary cost benefit analyses are favorable projecting a 81% internal rate of return for the conservative assessment and 152% for the more optimistic scenario. The study notes the distinction between the benefits of first generation GM products, which primarily provide economic benefits to producers and consumers, whereas the second generation technology contributes to lower health care costs for society which may be less visible, but can have substantial economic impact.

8.5 Performance of Bt Maize in Spain

The first study to assess performance of commercial GM crops in Europe features Bt maize in Spain which has occupied 20,000 to 25,000 hectares annually (5% of national hectarage) since its introduction in 1998 (Brookes 2002). Spain grew 485,000 hectares of maize for grain in 2001, equivalent to approximately 10% of European hectarage; 90% of the maize hectarage in Spain is irrigated and Bt maize has been planted in the areas with medium to high infestations of European Corn Borer (ECB). It is estimated that about 25% of the maize hectarage suffer from high infestations and a further 40% from medium infestations. From 6 to 20% of the maize area in Spain is treated with insecticides for ECB at a cost of $18 to $24/hectare (1.00 Euro = US$ 0.99) for control through application of insecticide in irrigation water or $36 to $42/hectare for aerial applications. The average yield loss due to ECB, despite application of insecticides to 6 to 20% of the crop is 5 to 7%, with losses as high as 10% to 15% in some regions during years of high infestation.

Yield Increases

Yield increases for Bt maize are related to the level of infestation which will vary by region and year. In the areas of high infestation where insecticides were not previously used, yield gains are about 15% and 10% where insecticides were previously used. An average yield increase of around 6% has been reported for several regions with other regions with low level of infestation gaining only 1% in yield. Premium for Bt seed ranges from $18 to $31/hectare with the lower end of the range applying to the majority of purchases.

Overall Economic Gains

Reduced insect control costs that range from $24 to $101/hectare, offset with a premium of $19 for Bt maize seed, result in net overall economic gains of $5 to $82/hectare. In the Huseca region of Spain, net economic gains ranging from $66 to $327/hectare, with an average of $146/hectare are typical in the Sarinena sub-region where ECB levels are normally high. In the Barbastro sub-region, with low to medium ECB levels, there has been no net loss or gain for Bt corn over the last three years. At current maize prices, farmers who do not apply insecticide for ECB control require a gain of only 0.15 tonne/hectare (1.5% yield increase) before Bt maize starts to become profitable.

Other Benefits

Bt maize decreases production risk, and contributes to more stable yields that are not subject to variability from ECB damage and yield losses. From the famers' perspective the convenience of not having to spray insecticides and monitor borer populations is a plus. Other benefits include: reduced exposure to insecticides and lower level of mycotoxin levels, both of which have health implications; and potential environmental benefits associated with fewer applications of insecticide. The Bt maize technology is equally appropriate for small farms (20 hectares in Zaragossa region) and larger farms (50 hectares in Huseca region) and in Spain no segregation of GM maize is required because the grain is used for feed in the same regions where Bt maize is grown.

The study (Brookes 2002) reports that provided Bt is available in the leading maize varieties, 36% (173,000 hectares) of the maize hectarage in Spain could be planted to Bt maize in the future. Assuming a 5 to 7% yield advantage for Bt maize over conventional maize, this could result in an increase of 88,000 to 123,000 tonnes, equivalent to a 1.8% to 2.5% increase in national maize production, with an increased additional annual value of $11 to $15 million. Assuming that current foliar insecticides applied to maize are only for ECB control, the potential increase in production and productivity would coincide with a net reduction of 59,000 to 98,000 hectares of maize sprayed with foliar insecticides. This would result in savings in insecticide of 35,000 to 40,000 kg a.i. - equivalent to a reduction of 26 to 45% of all insecticides (a.i.) applied to maize in Spain. If some foliar sprays were required for the control of other maize insects, a reduction of approximately one third of the above estimates would be realized.

In summary, the performance of Bt maize in Spain, reported by Brookes (2002) is positive and consistent with the corresponding assessment for Bt corn in the US. In 2001, Bt maize occupied 20% of the maize area in the US, compared with 5% in Spain but where the potential for the latter is estimated to be 36% of the Spanish national hectarage. The economic benefit per hectare in the US for 2001 was $22 per hectare compared with potential benefits in Spain in the range of $5 to $82 per hectare, with an average gain of $146 per hectare in the high infestation regions of Huseca. Thus, the assessment of the potential benefits of Bt maize in Spain (Brookes 2002) is positive due to the agronomic, environmental and economic benefits that it can deliver and consistent with experience with Bt corn in the US over the last five years.

8.6 China's Investments in Crop Biotechnology

China has 70,000 scientists in its agricultural research system of which approximately 2,000 are dedicated to crop biotechnology (Huang et al 2002).Work was initiated on crop biotechnology in the mid 1980s. A program on rice genomics was started in 1997. Chinese biotechnologists are amongst the world leaders in crop biotechnology and conduct research on more than 50 crop species utilizing more than 120 genes. Field trials have been conducted on 16 crops, some of which, like Bt cotton have been commercialized and adopted by up to 5 million small farmers in 2001. The range of crops (Table 21) includes all the major food/ feed crops: rice with insect, disease and herbicide tolerance traits; maize with improved quality and insect resistance; soybean with herbicide tolerance; wheat with improved quality and resistance to barley yellow dwarf virus; potato with improved quality and disease resistance. Orphan crops and vegetables such as virus resistant papaya, cabbage, chili and sweet pepper, all of which are generally assigned low priority in the global R&D agenda, are much more important for China and other developing countries. Resistance to the biotic stresses associated with viruses, insects, and diseases are the most important traits for China. Accordingly, 30% of the 26 GM applications listed in Table 21 confer improved virus resistance, 20% to insect resistance, 15 % to disease resistance, 12% to quality traits, 7% to herbicide tolerance and the balance with less than 5% each to salt tolerance, cold tolerance, shelf life and color change in petunias.

China was investing $ 112 million/annum on crop biotechnology in 1999 and plans to

Table 21. China's 26 GM Crops Applications (Commercialized and in Trials) in 2001

Trait	Crops
1. **Virus resistance** (8 crops)	Wheat, BYDV
	Peanut
	Cabbage
	Tomato
	Melon
	Sweet Pepper
	Chili
	Papaya, PRSV
2. **Insect resistance** (5 crops)	Cotton, Bt and CpTi
	Rice, Bt
	Wheat
	Maize
	Tobacco, TMV and CMV
3. **Disease resistance** (4 crops)	Cotton
	Rice
	Potato
	Rape Seed
4. **Quality improvements** (3 crops)	Wheat
	Maize
	Potato, starch improvement
5. **Herbicide tolerance** (2 crops)	Rice
	Soybean
6. **Salt tolerance** (1 crop)	Rice BADH
7. **Cold tolerance** (1 crop)	Rice
8. **Shelf life** (1 crop)	Tomato
9. **Color change** (1 crop)	Petunia

Source: Modified from Huang et al., 2002 and James, C., 1999. BADH betaine aldehyde dehydrogenase, BYDV barley yellow dwarf virus, PRSV Papaya Ringspot Virus, TMV Tobacco Mosaic Virus, CMV Cucumber Mosaic Virus, CpTi Cowpea Trypsin increase its investments by 400% by 2005. The Ministry of Science and Technology is the principal investor in biotechnology in China, and it increased its investment in crop biotechnology from $ 8 million in 1986 to $ 48 million in 1999. China allocates a high proportion, 9.2%, of its national crop R&D budget to crop biotechnology. Whereas China's budget for R&D in crop biotechnology represents more than half the corresponding investments of all developing countries estimated at $ 180 million, it is currently less than 5% of crop biotechnology investments by industrial countries (Huang et al 2002). However, taking into account China's planned increase of 400% in crop biotechnology expenditures by 2005, this will bring China's investment close to $ 0.5 billion, equivalent to 10% of current global R&D expenditures in crop biotechnology, and more in line with its 20% proportion of world population.

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.

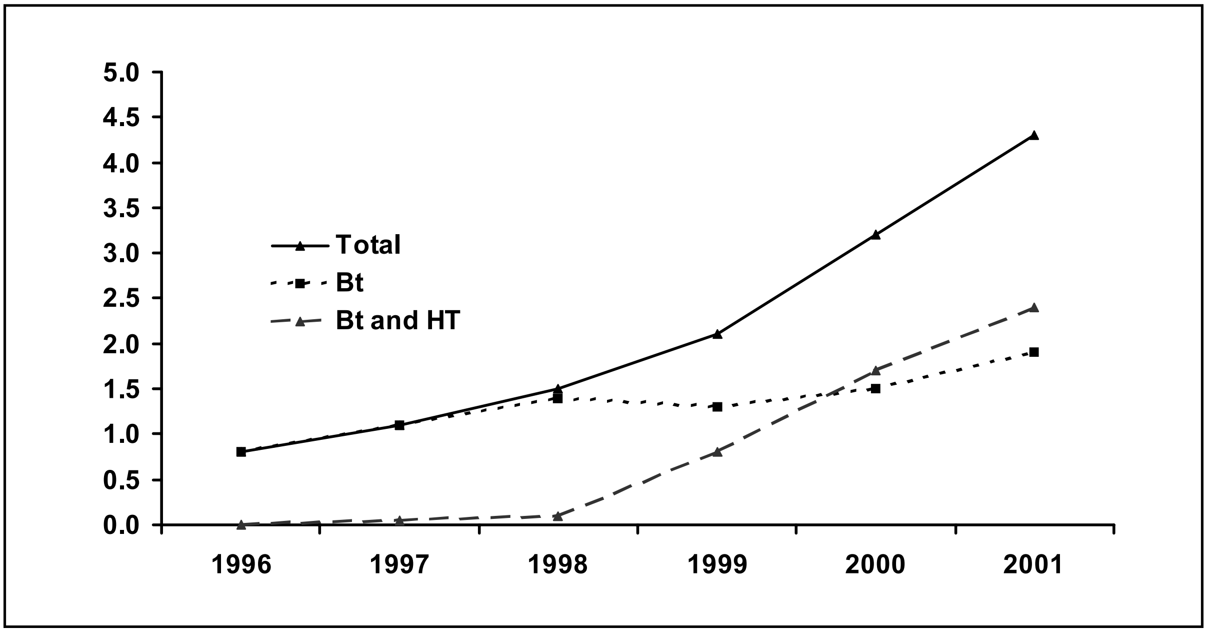
9.10 Global Adoption of Bt Cotton

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