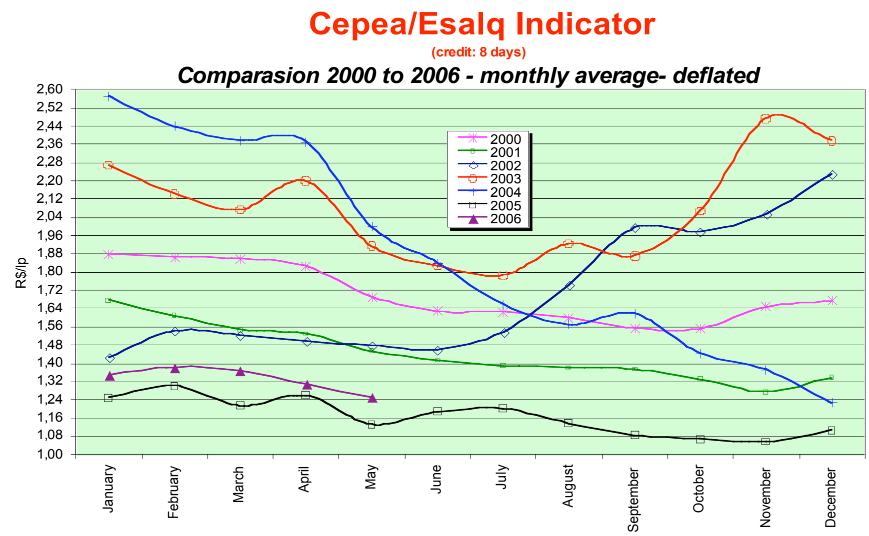
Figure 4 - Prices Achieved for Cotton in Brazil from 2000 to 2006.



Figures deflated by IGP-DI Brazil, Based value on May/2006 = 1.00

The Role of Biotechnology in Improving the Sustainability of Cotton

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Abstract

Population growth will drive a growing demand for textile fiber that will be either met by natural fibers, such as cotton, or by manmade synthetic fibers. Increasing global land area grown to cotton is not a sustainable alternative to meet this demand, thus modern technology is needed to maximize production per hectare in the most sustainable manner possible. Modern biotechnology is being adopted at a rapid pace globally in cotton. Growers realize the benefit of biotech cotton, either in reducing inputs or improving productivity, or both. In many cases, the reductions in inputs are accompanied by very positive impacts on cotton sustainability. Positive environmental benefits from cotton biotech are well documented and significant. Quality of life is improved by reducing exposure of field workers to pesticides and a general overall reduction in labor required per bale of cotton produced. Increasing yield with biotech cotton adoption, while decreasing pesticide costs has dramatically improved cotton profitability in many growing regions of the world. The impact and rate of adoption of cotton biotech will likely accelerate in developing countries and in small land holdings, due to significant potential improvements to sustainability. The pillars of sustainable production systems include: crop rotation, integrated pest management (IPM), and use of alternate or multiple technologies. The careful integration of cotton biotechnology into proven IPM systems and best cultural practices will be the most likely route to improved sustainability. It is essential to sustainability that biotech cotton be viewed as one important component of an integrated farming system.

Introduction

The increasing world population and changes in consumption patterns are projected to contribute to an annual growth in total textile fiber demand of 3-4 % per annum. An ever-increasing portion of that demand is being supplied by manmade synthetic fiber. Synthetic fiber production can simply accelerate production by building more factories, as is the case for the past decade. The land area for cotton production has been limited to 30 to 35 million hectares since 1974 and is unlikely to increase significantly to address this demand. Over farming and soil erosion are constant threats to existing cotton acres in certain regions of the world. In this context, concern for the environment is legitimate and must be viewed from the perspective of sustainability. The challenge of sustainability in cotton production is unique compared to other crops since there clearly is a competing product or textile fiber manufactured chemically from synthetic compounds, often from petroleum based products. If an affordable global supply of cotton is not reliably grown, it will be displaced by synthetic manmade chemical fiber. That is not the challenge for any other major agricultural commodity!

Sustainability is a concept that is misunderstood and misused by many. The sustainability of cotton cannot be improved by focusing on any single aspect of cotton production. It involves the entire agricultural production system for crops and animals. There is great diversity among farms and farmers around the world. Growing environments and the biological challenges to cotton production differ dramatically. Sustainable cotton production tries to achieve three goals:

- to effect the environment in a positive way,
- to be economical and profitable,
- and to enhance the quality of life.

Where these goals intersect, the net effect comes the closest to meeting the goals of sustainability (Cantrell, 2006). This concept of sustainability is very useful for comparing alternative agricultural systems. The differences are relative and not absolute. Sustainable cotton production should:

- supply a growing demand for fiber and food today and tomorrow,
- maintain an environmental and natural resource base upon which the agricultural economy depends and,
- sustain economic viability of farming operations.

The retail trade and brands have brought considerable attention recently to sustainability, often associated with discussion of organic cotton. Unfortunately, many either ignore or eschew the environmental benefits of modern technology, such as biotechnology. Modern advances in biotechnology offer considerable opportunity for addressing the improvement of cotton sustainability. Sustainability is unattainable if cotton producers are denied access to or choices of modern technology tools. Sustainability is equally unattainable if biotechnology is looked at as a silver bullet and replaces key pillars, such as integrated pest management, or breeding of adapted varieties. Biotechnology should be considered as a part of interdependent and converging technological systems.

2005 marked the tenth anniversary of the commercialization of biotech crops. The United Nations Conference on Environment and Development in 1992 stated that biotechnology "*promises to make a significant contribution in enabling the development of, for example, better health care, enhanced food security through sustainable agricultural practices, improved supplies of potable water, more efficient industrial development processes for transforming raw materials, support for sustainable methods of forestation, and detoxification of hazardous wastes.*" The number of countries growing approved biotech crops (cotton, maize, soybean and canola) grew to 21 in 2005. Fourteen of these countries have areas grown to biotech crops greater than 50,000 hectares. Of the farmers growing these crops, approximately 90% were resource-poor from developing countries (Clive James, 2005 "Global Status of Commercialized Transgenic Crops:2005" ISAAA Brief No. 34 (Ithaca, NY). Cotton growers have adopted biotechnology at a faster pace than growers of any other crop. Ten countries, representing over 60% of the global area of cotton production, currently allow biotech cotton to be grown: Argentina, Australia, Brazil, China (Mainland), Colombia, India, Indonesia, Mexico, South Africa, and United States. In 2005/2006, it is estimated that 28% of the global area of cotton production is planted to varieties containing biotech traits, such as insect and/or herbicide resistance. According to ICAC, this constitutes about 37% of total bales produced globally and about 38% of all exported bales. In the United States in 2006, Fernandez-Cornejo (2006) estimates that 83% of planted acres are grown to biotech cotton cultivars.

Biotechnology innovations in cotton have focused so far on input traits. These are developed with the goal of reducing producer inputs. Insect resistant (IR) cotton contains gene or gene(s) for control of *Lepidopteron* insects while herbicide resistant (HR) cotton contains genes that protect the plant against broad-spectrum herbicides. Cotton varieties are now available that stack multiple traits (IR and HR). Biotech research is ongoing to improve output traits, such as: agronomic performance, fiber quality, abiotic stress tolerance, and seed gossypol reduction. The objective of this paper is to discuss the role of current and future biotech traits in the improvement of cotton sustainability. The focus will be on the impacts on each of the components of sustainability: environment, quality of life, and profitability.

Cotton Biotechnology and the Environment

This issue encompasses two critical debates: the benefit of biotech cotton to the environment weighed against the safety risk for the environment or lack of harm. Biotech cotton compared to their conventional counterparts has led to significant reductions in pesticide use in countries where they are adopted. The reduction in pesticide inputs and reduction in yield losses from pests are the primary goals of IR and HR cotton. The amount of pesticide reduction and accompanying yield gain varies greatly with environment and pest pressure along with the complex mix of pests. The effects of biotech cotton relative to conventional counterparts have been extensively studied in small experimental research plots and increasingly in farm and system scale analysis. An exhaustive review of the changes in pesticide use patterns related to biotech cotton is presented by Carpenter et al. "Comparative Environmental Impacts of Biotechnology-Derived and Traditional Soybean, Corn, and Cotton Crops," Council for Agricultural Science and Technology, June 2002.

The major impact of the adoption of IR cotton in the United States is the reduction in insecticide use. For six U.S. states, the use of insecticides for IR cotton target pests declined by 12,000 tons between 1995, the year before IR cotton was introduced, and 1999 (Carpenter and Gianessi, 2001). This amounts to over a 14% reduction in the first few years of technology adoption. This amounts to almost 15 million fewer applications of pesticide in these six states. It was observed that treatments for other insects increased on IR cotton acreage. Secondary pests often emerged in IR cotton with the reduction of use of broad-spectrum insecticides. However, the reduction in treatments for IR cotton target pests is larger than the increased number of applications for secondary pests. Reduced use of pesticides can significantly decrease their effects on water quality through run-off and leaching of residues into surface and groundwater. Run-off water from U.S. fields planted with IR cotton was virtually free of insecticides during a four-year U.S. Department of Agriculture study. Large 2-year farm scale evaluation of IR cotton on 81 commercial fields in Arizona demonstrated a 40% reduction in the number of insecticide applications for IR cotton relative to conventional varieties (Cattaneo *et al.* 2006). In addition to this benefit, an 8.6% yield benefit was realized with IR cotton. The replacement of broad-spectrum insecticides with IR cotton had a very positive effect on biodiversity, including non-target beneficial insects.

Qaim and Zilberman (2003) reported that IR cotton hybrids reduced insecticide requirements by 70% in India relative to conventional hybrids while increasing yield over 80%. India has rapidly adopted IR technology in recent years. In 2006, 1.3 million ha were planted to IR cotton out of a total 8.8 million ha cotton crop. The biotech cotton area is projected to increase to almost 3.2 million hectares in 2007, or approximately one-third of total cotton area in India. Biotech cotton was first commercialized in China in 1997. Total area grown to IR cotton in 2005 was estimated to be 3.3 million ha or 60% of total cotton area. This means over 7.5 million farmers grow biotech cotton in China (Mainland) alone. This technology has resulted in a reduction in pesticide use of 15,000 tons or 60-80 percent (Pray et al. 2002).

Environmental impact is commonly communicated as change in quantity of pesticide applied or number of applications in a production system. A more robust measure for biotech crops is the *environmental impact quotient* (EIQ) proposed by Kovach et. al (1992). The EIQ is based on key toxicity and environmental exposure data related to individual pesticides, as applicable to impacts on farm workers, consumers, and ecology. This provides a single field value by multiplying the EIQ by the amount of pesticide active ingredient (ai) applied per hectare. It is nearly impossible to take into account all possible environmental issues and impacts, thus this value is more useful for comparison of production systems than as an absolute value. Brookes and Barfoot (2005) used the EIQ to estimate the impact on the use of herbicides and insecticides from growing biotech cotton globally from 1996-2004 (Table 1). The gains for IR cotton were the largest of any crop on a per hectare basis. Cotton farmers have used 77,000 tons less insecticide in IR cotton for a total reduction of 15% since 1996. This dramatic decline has resulted in a 17% decrease in the environmental quotient. The most dramatic reduction in the environmental impact of biotech cotton has occurred in the United States, Australia, and China (Table 2). This is not surprising, since these were the earliest adopters of the technology.

Table 1. Changes in Pesticide Use Due to Adoption of Biotech Cotton Globally from 1996-2004 (Brookes and Barfoot, 2005).

Trait	Pesticide amount	Change in pesticide (ai)	Change in EIQ
	(million kg)	%	%
HT Cotton	-24.7	-14.5	-21.7
IR Cotton	-77.3	-14.7	-17.4

Table 2. Change in EIQ for Selected Countries Associated with Adoption of Biotech Cotton from 1996-2004 (Brookes and Barfoot, 2005).

Country	HT cotton	IR cotton
	(% reduction in EIQ)	(% reduction in EIQ)
United States	23	20
Argentina	n/a	6.4
South Africa	5	n/a
China (Mainland)	n/a	28
India	n/a	2.1
Australia	3	21.2

n/a – data not available.

The adoption of HR cotton has lead to significant increases in acreage grown to conservation tillage. The environmental impact of conservation tillage is well documented. The use of conservation tillage reduces soil erosion by wind and water, increases soil water holding capacity, reduces soil degradation, reduces water and chemical runoff, and sequesters CO_2 in the terrestrial biosphere. HR cotton has expanded use of conservation tillage practices in the U.S to approximately 60% of total cotton acreage (USDA-NASS, 2004). Depending on the region and climatic conditions, the conservation tillage practices vary. The Conservation Tillage Information Center estimates that no-till cotton acres increased almost 400% from 1996-2004 in the U.S. Fuel and labor savings from planting HR cotton in the U.S. in 2004 approached US$48 million (Sankula *et al.* 2005). Seventy-nine percent of cotton growers surveyed by the Doane Marketing Research Group responded that HR cultivars were the primary reason for this increase in cotton no-till production.

Reduced or no-till systems can play a significant role in mitigating the effects of global warming by sequestering carbon in crop residue and reducing CO_2 emissions into the atmosphere. The amount of carbon sequestered varies by soil type, cropping system, and eco-region. In North America, the International Panel on Climate Change estimates that no-till systems save 300 kg carbon per hectare, reduced tillage systems save 100 kg carbon per hectare, and conventional tillage systems deliver a loss of 100 kg carbon per hectare (Brookes and Barfoot, 2005). Global CO_2 savings arising from the impact of biotech cotton is estimated to be 61,000 tons for the period 1996-2004, or an amount equivalent to removing 27,111 cars from the road.

Clearly, for biotech cotton to contribute to sustainability there should be minimal risk of harm to the environment. A transparent, rigorous, and coordinated regulatory system must be in place to test for possible ecological risks beyond food safety, such as:

- Gene flow or escape to related species
- Resistance management program for target pests
- Impact on non-target organisms
- Whether the biotech cotton will persist in the environment, especially longer than usual or invade new habitats.

The assessment is routinely conducted by the biotech developers, government regulatory bodies and academic scientists according to principles developed by environmental experts around the world (OECD, 1992, Safety Considerations for Biotechnology, Paris). The risks will vary dramatically from region to region, and assessments should be developed specific to a geographic region. The regulation, approval, and monitoring process for new biotech traits should be rigorous, transparent, and continuous for the life of the technology. Numerous countries have well-developed and enforced biosafety risk assessment frameworks. There seems to be little doubt that the products of modern cotton biotechnology are the most rigorously evaluated of any technology ever introduced (Fitt *et al.*, 2004).

Cotton Biotechnology and Quality of Life

The component of sustainability pertaining to "quality of life" is often overlooked or diminished. This is, in part, due to the diverse array of cultural and regional differences under which cotton is grown. The two most obvious areas of impact are improvements in safety to human health through reduced pesticide use and exposure and reduction in labor requirements. China (Mainland) and South Africa provide the most dramatic evidence of the human health benefits of adoption of IR cotton. Recent evidence from China demonstrates the direct human health advantage of biotechnology-derived cotton among farmers. Incidences of symptoms of pesticide poisonings were significantly reduced among those who planted *Bt* cotton compared to farmers of traditional varieties (Huang et al. 2001). There is estimated to be at least an 80% reduction in spray applications for bollworm control. Benefits would likely be similar or greater for resource-poor countries where small landholders use inadequate pesticide application technologies (Fitt *et al.*, 2004).

Sustainability, as measured by quality of life, certainly is affected by availability of a stable and affordable food supply. Biotechnology is progressing rapidly with tools to silence gossypol in cottonseed while maintaining levels in other plant tissue. Currently this cardio- and hepatotoxic terpenoid, present in the glands, renders cottonseed unsafe for human and monogastric animals. This will transform cottonseed into a viable human food source. The 44 million metric tons (MT) of cottonseed (9.4 million MT of available protein) produced each year could provide the total protein requirements of half a billion people for a year (50 g/day rate) if the seed were safe for human consumption. Thus, a gossypol-free cottonseed would significantly contribute to human nutrition and health, particularly in developing countries, and address food requirements of the predicted 50% increase in the world population in the next 50 years.

Reduced labor requirements often result from adoption of biotech cotton. Less labor requirements for pest control applications can translate into improved sustainability if opportunities exist in communities for education, economic development, and employment. Expanded or excess labor is particularly socially unacceptable if child labor is required. It is unfair to target biotech as potentially displacing farm laborers. If socioeconomic conditions require farm labor and flow-on community benefits are blocked, then the situation should be viewed as "subsistence farming" in the short-term. Sustainability can be reached, but it requires socioeconomic change on a grand scale far beyond the scope of agricultural biotechnology. It is hard to envision a sustainable production system that has as a goal to maintain labor required to produce a bale or to even increase labor requirements. This is counter to economic growth, and over-reliance on agriculture for employment will eventually lead to a cycle of subsistence farming. Biotech cotton integrates with other technology, such as mechanical harvesting and planting, to accelerate the decline in labor requirements per bale of cotton produced. Simultaneous improvements in productivity and reduction in labor inputs have contributed to a situation in the U.S. where it takes approximately 3 hours of labor to produce a bale of cotton, compared to over 25 hours prior to introduction of biotech cotton (USDA-NASS, 2004). Strict minimum wage laws and immigration reform affecting availability of farm laborers have mandated this decline. The rate of reduction in labor requirements will vary dramatically with local conditions.

Cotton Biotechnology and Economic Profitability

Cotton producers are driven by a relentless pursuit of decreasing input costs while maximizing productivity. The role cotton biotechnology plays in profitability will determine the extent to which it contributes to sustainability. Recent economic studies have reported highly variable and often positive economic returns attributable to biotech cotton adoption. The level and distribution of economic benefits are determined as much by national research capacity, intellectual property rights, and agricultural input markets as the biotechnology itself.

In the U.S. where biotech cotton was first adopted, several surveys have demonstrated that growers are achieving higher yields from IR cotton and attaining higher profit. The average increase in net returns from 5 studies in 7 states comparing IR cotton to conventional cotton was US$8.42/ha, taking into account the technology costs. The average yield increase was 9%. With these yield gains and revenue, the projected benefit of IR cotton in the U.S. was US$99 million in 1999 alone (Carpenter and Gianessi, 2001). New generation IR cotton with stacked genes may provide additional economic returns. In 2004, the net grower returns in the U.S. due to planting new stacked gene IR cotton was estimated at US$13.7 million. The economic advantage was US$28.70 and US$4.23 per hectare, respectively, compared to conventional and single-gene IR cotton (Sankula et al. 2005: Mullins *et al.* 2005).

Raney (2006) summarized the results from the most comprehensive study of the farm-level impacts of IR cotton in developing countries (Table 3). A positive overall result is demonstrated despite large temporal and spatial variation. Farmers growing biotech cotton (IR) experienced higher effective yields due to lower pest damage from target insects. This accompanied higher revenue and reduced pesticide costs. The higher cost of IR seed was offset by these factors.

In 2005, India experienced the highest proportional annual growth for any biotech crop globally with IR cotton expanding 160 percent. Approximately, 1.3 million ha were planted to IR cotton hybrids by more than one million farmers (ISAAA, 2005). Wide-scale cultivation of IR cotton in India has been the focus of intense scrutiny and debate. The Indian Council of Agricultural Research (ICAR) has conducted multi-location field trials for cost-benefit analysis of IR cotton. Yield increases, relative to local and national checks, ranged from 62% to 92% (Table 4). The advantage in gross income averaged 67% while adjusting for seed costs, the net economic advantage of IR cotton ranged between US$105.2/ha and US$231.9/ha (ISAAA, 2002, Table 4). As IR cotton acreage expands in India, more farm-scale data rather than research-plot data is emerging (APCoAB, 2006, Table 5). The overwhelming yield gains frequently offset higher seed costs, and the reduction in pesticide use is over 70% compared to conventional cotton hybrids.

The consumer may benefit from modern technology as well as farmers, seed suppliers, and technology providers. Biotech developers and seed companies benefit by charging technology fees and seed premiums to adopters of modern varieties. U.S. and foreign consumers may benefit indirectly from biotech crops through lower commodity prices that result from increased supplies. USDA-ERS estimated the total market benefit arising from Bt cotton and herbicide tolerant (HT) cotton (Price et al., 2003). The total estimated benefit for HT cotton was $230M in 1997. This estimate includes the change in total welfare in both the seed input and commodity output markets. Surprisingly, adoption of HT cotton primarily benefits the consumer, with a consumer stakeholder share of 57 percent.

Challenges to Improving Sustainability with Cotton Biotechnology

The evolution of resistance in the target pest (weed or insect) is one of the major challenges to the sustainable use of HT or IR cotton. A "case-by-case" system of management is critical for the sustainability of the technology. Fortunately, resistance has not developed in target insects on a field-scale to IR cotton that has been grown on large areas in some countries for almost 10 years. The deployment of resistance management systems specific to cropping systems and alternative hosts of the target insects has contributed to this success. Structured refuge has been deployed effectively as an insect resistance management strategy, along with stacked gene systems, to delay resistance development. The emergence of certain secondary insect pests can erode the benefits of IR cotton as demonstrated by Wang and et al. (2006) in China. Appropriate refuge and educational programs on the threat of secondary pests are needed for sustainable development of IR technology. Knowledge

Table 3. Performance Advantage of IR Cotton over Conventional Cotton Expressed as a Percentage (Raney, 2006)

	Argentina	China	India	Mexico	South Africa
Yield	33	19	34	11	65
Revenue	34	23	33	9	65
Pesticide costs	-47	-67	-41	-77	-58
Seed costs	530	95	17	165	89
Profit	31	340	69	12	299

Table 4. Performance of IR Cotton Hybrids in ICAR Field Trials in India (ISAAA, 2002 and APCoAB, 2006).

Variety/hybrid	Yield	Gross Income	Insecticide cost	Additional seed costs	Net income
	q/ha	$/ha	$/ha	$/ha	$/ha
MECH-12 Bt	11.67	477.4	39.3	55.1	383.0
MECH-162 Bt	13.67	559.2	32.1	55.1	472.0
MECH-184 Bt	14.00	572.7	32.1	55.1	485.5
Local Check	8.37	342.4	64.7	-	277.8
National check	7.31	299.1	45.5	-	253.6

Table 5. Performance of IR Cotton from 9,000 Farms in 2002 and 2003 in Maharashtra (Bennett *et al.* (2004).

Type of hybrid	Sprays for bollworm control		Yield gain relative to non-Bt		Gross margin
	2002	2003	2002	2003	2003
IR Cotton (Bt)	1.44	0.71	45%	63%	US$1156.90
Non-Bt	3.84	3.11	-	-	US$665.40

of effective control and IPM strategies for certain secondary pests is lacking, thus research is needed in that area. Strategies should be undertaken by governments, research agencies, and technology providers on a regional basis that minimize the burden on local farmers.

Problems have been encountered with certain weeds developing moderate to high levels of resistance to glyphosate in HT cotton fields in the U.S., especially in reduced tillage production systems. At least two major weed species have documented glyphosate resistance in isolated areas of the Southeastern and upper mid-south U.S. (International Survey of Herbicide Resistant Weeds, http://www.weedscience.org). The risk of HT cotton, and possibly IR cotton, is to view biotechnology as a "silver bullet." This can lead to erosion of the pillars of sustainable productions systems; such as crop rotation, integrated pest management (IPM), and use of alternate or multiple technologies. The careful integration of cotton biotechnology into proven IPM systems (FAO, 2002) and best cultural practices will be the most likely route to improved sustainability.

Sustainability of biotech cotton is jeopardized by technology not always being available in adapted local germplasm. The length of time and cost to introgress biotech traits into local adapted cultivars and hybrids, plus intellectual property rights issues exacerbate this problem. New technology, such as DNA markers, are being applied to the development of biotech cotton that can reduce the time to introgress a trait and better preserve the target genetic background for local adaptation. As more information emerges on the cotton genome, these tools for marker-assisted selection will be broadly available through the International Cotton Genome Initiative (http://icgi.tamu.edu). Just as for IPM, there is a risk that conventional germplasm breeding efforts will be displaced in the era of biotech cotton. It is essential to sustainability that biotech cotton be viewed as one important component of an integrated farming system.

References

APCoAB (2006) Bt cotton in India – A status report. Asia-Pacific Consortium on Agricultural Biotechnology, New Delhi, India. p 34.

Bennett, R.M., Ismael Y. Kambhampati, V., and S. Morse. 2004. Prospects for Bt cotton technology in India. AgBioForum 7:96-100.

Brookes, G., and P., Barfoot. 2005. GM Crops: The global economic and environmental impact – The first nine years 1996-2004. AgBioForum 8(2&3):187-196.

Cantrell, R.G. 2006. A focus on sustainability. Engineered Fiber Selection Conference, June 2006. (http://www.cottoninc.com/Sustainability/FocusonSustainability/).

Carpenter, J., A. Felsot, T. Goode, M. Hammig, D. Onstad, and S. Sankula. 2002. Comparative environmental impacts of biotechnology-derived and traditional soybean, corn and cotton crops. Council for Agricultural Science and Technology (CAST), Ames, IA, p 198. June, 2002.

Carpenter, J. and L.P. Gianessi. 2001. Agricultural biotechnology: Updated benefit estimates. National Center for Food and Agricultural Policy, Washington, DC. p 46 (http://www.ncfap.org).

Cattaneo, M.G., C. Yafuso, C. Schmidt, C. Huang, M. Rahman, C. Olson, C. Ellers-Kirk, B.J. Orr, S.E. Marsh, L. Antilla, P. Dutilleul, and Y. Carriere. 2006. Farm-scale evaluation of the impacts of transgenic cotton on biodiversity, pesticide use, and yield. *Proc. Natl. Acad. of Science* 103(20):7571-7576.

FAO. 2002. International code of conduct on the distribution and use of pesticides. http://www.fao.org/ag/AGP/AGPP/Pesticid/Code/PM_Code.htm (Adopted by the Hundred and Twenty-third Session of the FAO Council in November 2002).

Fernandez-Cornejo, J. 2006. Adoption of genetically engineered crops in the U.S. Data Product. U.S. Department of Agriculture, Economic Research Service. http://www.ers.usda.gov/Data/BiotechCrops/. June 2006.

Fitt G.P., P.J. Wakelyn, J.M. Stewart, D. Roupakias, J. Pages, M. Giband, Y. Zafar, K. Hake, and C. James. 2004. *Report of the Second Expert Panel on Biotechnology in Cotton,* International Cotton Advisory Committee (ICAC), Washington, DC, USA, Nov. 2004.

Huang, J., S. Rozelle, C. Pray, and Q. Wang. 2001. Plant biotechnology in China. *Science* 295:674-678.

James, Clive. 2002-2005. Global Status of Commercialized Biotech/GM Crops: ISAAA, Ithaca, NY, USA

Kovachs, J., C. Petzoldt, J. Degni, and J. Tetti. 1992. A method to measure the environmental impact of pesticides. *New York's Food and Life Sciences Bulletin*. Geneva, NY:NYS Agricultural Experiment Station, Cornell University, (http://www.nysipm.cornell.edu/publications/eiq/).

Mullins, W., D. Pitts, and B. Coots. 2005. Sister-line comparisons of Bollgard II versus Bollgard and Non-Bt cottons. 2005 Beltwide Cotton Conference. p 1822-1824.

Pray, C., Huang, J, Hu, R, and Rozelle, S (2002) Five years of Bt cotton in China – the benefits continue. *Plant J* 31:423-430.

Price, G.K., W. Lin, J.B. Falck-Zepeda, and J. Fernandez-Cornejo. 2003. The size and distribution of market benefits from adopting agricultural biotechnology. U.S. Department of Agriculture, Economic Research Service, *Technical Bulletin* No. 1906. Nov. 2003.

Qaim, M., and D. Zilberman. 2003. Yield effects of genetically modified crops in developing countries. *Science* 299:900-902.

Raney, T. 2006 Economic impact of transgenic crops in developing countries. Current Opinion in Biotechnology 17:1-5.

Sankula, S., G. Marmon and E. Blumenthal. 2005. Biotechnology-derived crops planted in 2004 – Impacts on US agriculture. National Center for Food and Agricultural Policy, (http://www.ncfap.org/whatwedo/pdf/2004biotechimpacts.pdf), December 2005.

Wang, S., D.R. Just and P. Pinstrup-Anderson. 2006. Tarnishing Silver bullets: Bt technology adoption, bounded rationality and the outbreak of secondary pest infestations in China. American Agricultural Economics Association Annual Meeting, Long Beach, CA. July 22-26, 2006.

~~Sustainability: Key to the Australian Cotton Production Practices~~

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~~(Presented by Richard Browne)~~

~~Summary~~

~~The Australian cotton industry can clearly demonstrate the capacity to support a productive, profitable and sustainable production system, but many challenges remain. There is a realization that future success will only be achieved by understanding the internal and external influences that will shape the future of the industry. Internal factors will include the pressure of ever increasing input costs and the cost of new technologies in particular. Competition for water will be an ongoing concern and of course commodity prices. Even more challenging perhaps will be external factors such as community perception and acceptance as well as a measure of environmental performance. This paper explores some of these issues within the Australian context, asks whether our conclusions have relevance to cotton production globally and, if they do, what might we do collectively to address them.~~

~~In the last ten years the adoption of biotechnology by Australian cotton growers has been extensive and this has led to a number of significant changes to production practices. Key outcomes have included significant reductions in the use of most insecticides and miticides as well as residual herbicides, and more certainty in management and costs for growers not withstanding ever increasing cost pressure. The positive impacts have included reduced pesticide contamination of river systems and neighbouring farms in cotton growing areas, improved worker safety and improved lifestyles of cotton growers and farm workers due to reduced pesticide application. (Critically however, while there has been an improvement in the public perception of the cotton industry in regional communities, the industry has yet to satisfactorily establish ongoing indicators of environmental performance that are fully convincing to the community at large.) The negative impacts of biotechnology have been on some types of agribusiness (eg. pesticide application contractors and chemical suppliers/distributors) and reduced requirement for casual labour (eg cotton chippers).~~

~~Biotechnology coupled with improvements to management have certainly contributed to a more sustainable system of cotton production in Australia. However, these improvements and many others introduced over the past decade in production~~