



## Impact of Transgenic Cotton

The original goal of transgenic Bt cotton was to achieve efficient, cost effective and environmentally safe pest control of major lepidopterous insects. The plant's ability to inhibit the multiplication of lepidopteron pests provides multiple benefits, like reduced use of insecticides; lower levels of air pollution; less waste production; improved safety of farm workers, particularly in countries where insecticides are sprayed manually; enhanced use of beneficial insects as biological control agents; lower cost of production and, ultimately, higher yield. Other benefits include the ability to control bollworms (lepidopteron) that have already developed resistance to insecticides and the ability to produce cotton in areas that have been abandoned due to uneconomical bollworm control costs. Some of these issues are discussed here in detail.

### Growers' Selection of Varieties

In most countries, growers can select varieties of their own choice for planting every year. There are premiums and discounts based on the quality of cotton to be produced from each variety. The trend in various countries shows that premiums and discounts are not enough to change farmers' decisions regarding variety selection. Farmers' decisions are primarily based on yield. Farmers are always excited to grow new varieties because new varieties are supposed to yield higher over existing varieties. Since the introduction of transgenic cotton, farmers' preference for varieties has changed. It is less based on the search for new and high yielding varieties and more on the availability of in-built resistance to insects and herbicides. The herbicide issue is particularly true for the USA but in other countries, like South Africa, smallholder farmers with low yields have shown great interest in cotton varieties that are genetically resistant to lepidopterous insects. In South Africa, transgenic insect resistant varieties were planted on 40% of the total cotton area in 2000/01. In China (Mainland), the *Helicoverpa armigera* resistant provinces in the Yellow River Valley have embraced Bt varieties without any hesitation and area has increased to million hectares in just a few years. Although Bt cotton guarantees protection against lepidopteron caterpillars only, and growers still have to spray against other

pests, the primary focus in selecting varieties has changed at the farmers' level from yield to assured resistance to insects. The rate of adoption of Bt cotton indicates the level of confidence in the in-plant toxin to control bollworms.

### Yield Increase

A great deal of information is available in the literature on yield increases due to Bt cotton. But there is a lot of variation in the extent of the increase, which is quite justified due to reasons discussed below. While there is no increase, there is also no decrease expected, because no negative correlation between the non-cotton gene with the cotton genome in the currently available transgenics has been detected so far. The range of increase will depend on many factors and will vary from year to year to some extent from variety to variety, location to location—that authentic and reliable yield data are not available for head to head comparisons. One set of data on fiber quality was presented at the 2000 Beltwide Cotton Conferences by Kerby et al (2000). More recently, Kerby (2001) reported on yield performance of transgenic and straight varieties. He has presented comparisons made on seven transgenic varieties versus their recurrent parents, grown together side by side under similar conditions in the same field. This provided a direct comparison across management and environments of a conventional parent to its corresponding transgenic genotype. The following data are the average of Deltapine varieties planted in small replicated trials.

The data is an indication of the performance of Bt gene varieties against their recurrent parents and is in no way a guarantee

Yield Comparison of Transgenic Versus Recurrent Parents			
Characteristic	Conventional (Kg/ha)	Transgenic (Kg/ha)	% Change Recurrent on Parents
Bollgard (Bt)	1,121	1,216	+9
Roundup Ready	1,177	1,157	-2.0
Stacked	1,209	1,259	+4

that such an increase or decrease in yield will be realized. The toxin expression varies from one location to another, from variety to variety, from time to time, and from one part to another plant part; accordingly, pest control will be affected and thus, yield.

## Why Yield May or May Not Increase Due to Bt Gene

The observation that Bt gene varieties will always out-yield their recurrent parents may be true for certain conditions but not for others. Even if it is proved year after year that transgenic varieties, particularly Bt varieties, produce higher yields, it should not be assumed that the addition of the Bt gene in the cotton plant will boost the plant's ability to produce a higher yield. The yielding ability of the cotton plant remains the same with or without the Bt gene. However, the ability of transgenic Bt plants to avoid bollworm losses due to host plant resistance enables them to grow more productive bolls compared to plants affected by bollworms. In conventional production, it is recommended to spray the crop with insecticides when the pest population has reached a particular economic injury level. This is a level when it is assumed that the economic benefit in yield is higher than the cost of insecticide and its application. But this is a stage when some loss in yield has already occurred due to bollworms. In contrast, Bt cotton can escape from such a loss and give higher yields because the toxin is always present in the plant.

The increase in yield from the use of Bt varieties depends on the number of times the economic threshold would be reached to spray against bollworms. If an economic threshold is never reached, but bollworms persist for a significant time during the boll formation stage, there may be some increase in yield. However, the increase would not be equivalent to the situation when an economic threshold is reached frequently during the season. The increase in yield in Bt varieties could serve as an indicator of how best a farmer has been controlling bollworms. If bollworms are among major pests, no increase or a minimum increase is a good indication that they are being controlled well. According to Joubert et al (2001), the fact that Bt cotton has become more popular among small farmers in South Africa, compared to large farmers, is testimony that bollworm control was not good under conventional practices.

The currently available Bt varieties have a single bacterial gene that is not able to control all bollworms. The cry1Ac gene in Bollgard® varieties in the USA and elsewhere, and Ingard varieties in Australia (all Bt varieties) have the ability to control mainly the tobacco budworm, the cotton bollworm and the pink bollworm. If these bollworm species do not exist or they never reach the levels close to the threshold, no increase in yield due to the Bt gene may be expected. The introduction of the Bollgard® II gene (cry2Ab) will enhance the ability of transgenic cottons to control more insects. The development of a multiple toxin system in transgenic plants, with toxin pyramiding that recognizes different binding sites, has not only reduced the

chances of resistance development but also enhanced the plant's defense against more species of insects. Accordingly, expectations that stacked gene Bt varieties will give higher yields have also increased. A comparison of the effectiveness of two Bt genes against various pests follows:

<b>Bollgard®</b> (cry1Ac)	<b>Bollgard® II</b> (cry2Ab)
<i>Heliothis virescens</i> (Tobacco budworm)	<i>Spodoptera frugiperda</i> (Fall armyworm)
<i>Helicoverpa armigera</i> (Cotton bollworm)	<i>Spodoptera exigua</i> (Beet armyworm)
<i>Pectinophora gossypiella</i> (Pink bollworm)	<i>Trichoplusia ni</i> (Cabbage looper)
	<i>Pseudoplusia includens</i> (Soybean looper)

## Natural Enemies

There are some concerns from countries, organizations and even individuals that do not encourage the production of transgenic varieties. However, these concerns are more related to food crops. As far as cotton is concerned, six years of commercial production of Bt varieties in the world has demonstrated that the Bt gene technology provides effective control of target insects. Herbicide resistant transgenic varieties are just now expanding to countries outside the USA, but the situation within the USA has confirmed its success. Although the long-term impact of some of the benefits, including the enhanced use of beneficial insects, has yet to be seen, the short-term indications are that Bollgard® cotton preserves more natural enemies compared to conventional spraying. Last year, Head et al (2001) started large-scale long-term studies to assess the relative impact of the Bt gene and conventional varieties treated with insecticides on the populations of beneficials in the field. They selected a number of fields in three states in the USA. Only comparable fields with fewer than four hectares were selected for monitoring. The arthropod population was monitored on a weekly basis in Bt and non-Bt fields throughout the cotton growing season. The population of natural enemies varied among locations, but in all cases the Bt varieties preserved more natural enemies and the population of predatory bugs, spiders and ants significantly decreased in fields where conventional insecticides were used as usual. The data are for one year and it remains to be seen what will happen in five years or more.

## Higher Cost of the Planting Seed

Transgenic seed is sold at a higher price because seed companies have to take extra care in ginning, delinting and seed treatment processes. Moreover, farmers have to pay a "technology fee," which is said to be the cost of savings on insecticide use. The company that owns the gene charges the fee, which currently is not the same in all countries. In Australia, it has changed from year to year, and in the USA it has been the same since 1996. The technology fee in the USA is US\$80/ha for the Bt gene, lower than in Australia, but extremely high for many other countries. There is no set formula to calculate the technology

fee, but it can roughly be related to the cost of insecticides used to control the affected bollworms. It seems that farmers in many countries will need financial help in the form of loans or advances to pay for the technology fee up front.

## Fiber Quality

The popularity of transgenic cotton varieties is due to improvements in insect pest management and additional options in weed control. The literature tells of no impact on fiber quality that could be related to a harmful effect of the Bt gene. If there are any minor changes in the reading for various characteristics, they could be due to a change in the location of bolls on the plant. Bt varieties provide bollworm control from the very beginning and protection from shedding due to early bollworm attack. Even if there is no increase in the number of bolls on the plant, their position/distribution will change, which could have an effect on fiber quality. The number of first-position bolls could change and the crop maturity could be affected, depending on the high rate of boll formation in the beginning.

## Economic Impact

The following conclusions can be drawn regarding the economic impact of transgenic cottons, particularly the Bt varieties.

- It is not economical to grow Bt varieties everywhere in all countries.
- The economic impact will depend on what kind of bollworms attack cotton and the level of pest pressure during flowering and boll formation stage.
- There is always a seasonal variation in pest pressure and, accordingly, the extent of economic benefits will vary year to year.
- The technology fee is an important factor in determining the economic benefits. If the technology fee is higher than the cost of insecticides used to control bollworms, Bt cotton may not become popular.
- The actual cost of pesticides is a crucial factor in deciding to use Bt cotton. If governments subsidize pesticides and there is no financial help for technology fees, growers may be reluctant to switch to Bt cotton.

Who will benefit most from the use of transgenic technology often depends on either the seed companies or the owners of the technology. The quick adoption of the technology in China (Mainland), the USA and other countries is a clear indication that growers are sharing the economic benefits of this technology. The situation in Mexico shows that growers are taking a good share of the economic advantage of Bt cotton. Bt cotton has been adopted in Mexico more easily than in other countries. Deltapine varieties were imported and used on a commercial scale. According to a report presented at the Fifth International Conference on the Economics of Biotechnology that took place in Ravello, Italy in June 2001—organized by the International Consortium on Agricultural Biotechnology

(ICABR) in cooperation with the University of Rome “Tor Vergata,” the Economic Growth Center of the University of Yale, New Haven, and the Center of Sustainable Resource Development of the University of California at Berkeley—under the Mexican situation, 85% of the total profit due to Bt varieties accrued to farmers, while 15% went to the seed companies.

## Need for Institutional Capacity in Biotechnology

Biotechnology is a comparatively new science, particularly with respect to its application in agriculture, and the introduction of transgenic cotton has changed the focus within the research systems in most countries. There are a number of limitations, which not only hinder the spread of this technology to other countries but also limit awareness of the technology within a country. The current motivation is inclined to promote products and not the science or principles under which such products are developed. Many countries are in the process of developing their own systems but they are faced with problems due to a lack of knowledge and experience, which in most cases lie with the private sector. Unlike many other disciplines of cotton production research, genetic engineering research is expensive, and developing countries—where most cotton is grown—cannot afford to set up basic research facilities. Buying the technology in the form of products ready for use, like Bt cotton, also carries a big price tag. Even if a country is ready to buy the technology in a finished form, it has to have biosafety regulations in place, without which a product unfit for local conditions could be spread.

The biotechnology system carries various stages of which the four most important are

- Research institutions/companies carrying research on genetic engineering of cotton
- Permission to conduct field trials
- Permission for limited commercial planting
- Approval for full commercial use

The process can be further extended to more committees and approvals, as is the case in Egypt. In the June 2001 issue of *THE ICAC RECORDER*, a detailed article was published on biosafety regulations in Egypt along with responsibilities of various agencies to introduce or research a biotechnology product. The process can also be narrowed to only three stages as in India, where the Review Committee of Genetic Manipulation, the Genetic Engineering Approval Committee and the Indian Council of Agricultural Research deal with reviews and approval of GE products for research and small scale trials, approve field tests for large scale projects and importation of GE crops for commercialization, and facilitate research and technology transfer. It is the responsibility of governments to develop such systems and to educate the public in their countries in the safe use of this technology.

All the transgenic cotton currently used was developed by the

### Regulatory Approval of Transgenic Cotton

Characteristic	Argentina	Australia	China (M)	Indonesia	Mexico	South Africa	USA
Bromoxynil (BXN)	-	-	-	-	-	-	1994
Roundup Ready (RR)	1999	2000	-	-	-	-	1995
Bollgard/Ingard (Bt)	1998	1996	1997	1999 (?)	1997	1997	1995
Insect Resistant Bt + Herbicide Resistant (RR)	-	-	-	-	-	-	1997

Note: Bt cotton is also called Ingard in Australia.

*Agrobacterium tumefaciens* mediated plant transformation method. The year of regulatory approval may be different from the year of commercial production.

## Reason for Bt Cotton in China (M)

In China (Mainland), two types of transgenic bollworm resistant cottons are grown: one is the same Bt cotton grown in other countries and the other has been developed locally. The adoption of Bt cotton in China (Mainland) was due to different reasons than those of other countries. China (Mainland) planted cotton on 6.5 million hectares in 1991/92 when the average yield was 867 kg/ha. The next year area increased to 6.8 million hectares and the average yield dropped to 660 kg/ha. Such a significant drop in yield is attributed to bollworm resistance to insecticides. The cotton bollworm developed resistance to most insecticides and it became difficult to control, particularly in the Yellow River Valley where yields dropped to less than 500 kg/ha in 1992/93. The number of sprays increased significantly and many farmers in the provinces most affected—Hebei, Henan and Shandong—could not afford to continue producing cotton. Consequently, the most affected area was taken out of cotton production. Cotton production expanded in the northwest region, which was traditionally a high yielding area.

Replacement of low yielding area with the high yielding area coupled with integrated pest management programs did show some positive impact on yields, but the average yield remained below one ton of lint until 1997/98. Since 1997, when Bt cotton was approved and started commercial production on a large scale, the average yield in China (Mainland) has been more than one ton of lint per hectare. At the national level, Bt cotton was planted on only 2% of the total area in 1998/99, increased to 14% in 1999/00, and almost to 25% in 2000/01. However, it is estimated that most of the area in the above-mentioned provinces is being planted with Bt varieties. The Bt cotton would

not have been adopted at such a fast rate in China (Mainland), had they not suffered heavy losses due to the insecticide resistance problem.

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