# US Reaction to Bt Cotton

Genetically engineered Bt crops were grown on commercial scale for the first time in 1996. Despite considerable controversy, the US Environmental Protection Agency gave the go-ahead in 1995 for Monsanto, Ciba-Geigy, and Mycogen to sell cotton, corn and potato seed for planting on commercial scale. The three crops were engineered to contain an insecticidal toxin from *Bacillus thuringiensis*, a soil bacterium. The development of insect resistant crop varieties is so far the most successful application of agricultural biotechnology research. The Bt transgenic crops contained a *Bacillus thuringiensis* gene, capable of producing the insecticidal protein CryIA throughout the life of the plant. The toxin is produced by both the plant and the bacterium gene working together. Transgenic cotton resistant to the herbicide bromoxynil was also introduced almost at the same time. Though herbicide tolerant cotton also derived its resistance to the herbicide from a gene transferred from a bacterium, the two transgenics did not affect each other. Roundup Ready herbicide-tolerant varieties were grown on a commercial scale for the first time in 1997. Different transgenics have been named differently and, currently, the following types of transgenic cotton are available for commercial production in the USA.

**Bt cotton** – It is the most commonly used name derived from *Bacillus thuringiensis* and applies to varieties resistant to insects only. Bt cotton is called Bollgard® in the USA and Ingard® in Australia. Currently, all Bt varieties have the same gene but many new genes are being explored for expanding the basis of resistance.

**BXN cotton** – Like weeds, cotton is also susceptible to herbicides. A gene was obtained from the soil bacterium *Klebsiella ozeanae* and inserted into cotton so that a broad-spectrum herbicide Buctril® could be sprayed over the crop. Such varieties are called BXN varieties. The bacterium gene codes for the enzyme nitrilase and is capable of removing nitrile atom from the compound and detoxifying bromoxynil. The most appropriate time for spraying the herbicide is at the 2 to 4 leaf stage but can be used until 75 days to harvest.

**Roundup Ready cotton** – Roundup Ready varieties are resistant to the herbicide Roundup Ultra in vegetative tissues but reproductive parts are susceptible. Roundup Ultra can be sprayed over the cotton crop to control a broad spectrum of weeds, particularly broad leaf weeds. Roundup Ready varieties contain a gene that provides the plant with an alternate pathway to produce the required essential amino acids. According to McD. Stewart (1991), resistance to glyphosate has been accomplished by two means: (1) placing of a strong constitutive promoter in front of a specific enzyme so that the enzyme is over-produced; and (2) making the enzyme insensitive so that aromatic enzymes are not produced. The most appropriate time for spraying the herbicide is not later than the 4-leaf stage or four nodes above the cotyledonary leaves.

**Bt + Roundup Ready cotton** – Two genes resistant to bud/bollworms and glyphosate herbicide have been inserted in one genotype. Such a variety is also called a “stacked gene variety” and is the first type of cotton that has at least two non-cotton genes. Roundup Ready insect-resistant transgenic varieties were planted on a commercial scale for the first time in 1998.

**Bt + BXN** – It is a mix of Bt and BXN non-cotton genes. Only one stacked gene variety, BG 4740 was available for planting during 1998.

**Area under Transgenic Cotton in the USA**

| Transgenic Cotton | 1996 | 1997 | 1998 |
|---|---|---|---|
| | | Million Hectares | |
| Bt cotton | 0.73 | 1.01 | 0.6 |
| BXN varieties | Seed production | 0.12 | 0.8 |
| Roundup Ready | Seed production | 0.32 | 1.2 |
| Bt + Roundup Ready | - | Seed production | 0.4 |
| Bt + BXN | - | Seed production | 0.2 |
| **Total** | **0.77** | **1.46** | **3.3** |

In the USA, cotton is planted in 16 states divided into four different regions: West, Southwest, Delta and Southeast. Production characteristics of these regions differ. Herbicide tolerant cotton having resistance to bromoxynil or glyphosate could be planted successfully in any area infested with broad leaf weeds. But, Bt cotton is not suitable for planting in all states in the USA. The toxin produced by the Bt gene is specific in action and most effective against tobacco budworm, *Heliothis virescens*. The toxin does have a toxic effect on many other species of bollworms but the mortality rate is not comparable to that of the tobacco budworm. Accordingly, the areas that are affected by bollworms, particularly tobacco budworm, are more suitable for Bt cotton.

## Need for Bollworm/Budworm Resistant Cotton

As in all other countries, cotton is attacked by a variety of insects in the USA. Since 1979, losses due to insects have been assessed at state and national level. At the time the survey was initiated, 20 years ago, boll weevil, boll/budworm, cotton fleahopper, lygus bug, cotton leaf perforator, pink bollworm, spider mite and thrips were important insects. Minor insects were included under “others.” While the “others” list has changed over time, aphids, beet and falls armyworm were added to the main insect list in 1989. In 1992, the European corn borer and sweetpotato whiteflies, now among the major insects in the Southeast and West respectively, were added to the main insects list. Now the list contains 21 insects responsible for economic losses to cotton in the USA (Williams, 1997).

Since 1979, in terms of losses in yield, the boll weevil has been a major pest only three times. Out of 18 times, 13 times boll/budworms caused more losses in yield than any other insect. Insect pressure varies from year to year and, accordingly, also the loss in yield due to a particular insect or group of insects. But, with the exception of only one year, boll/budworms have been either the first or second most important insect responsible for maximum loss in yield.

After many years of research it was concluded that boll weevil could be controlled successfully if it is attacked at the most vulnerable stage. Accordingly, the boll weevil eradication program was initiated in the USA and has proved successful in eliminating boll weevil in the Southeast and minimizing the population in many other states. Boll/budworms, which are in fact the major insects in the USA, require very careful monitoring of the pest population in addition to use of insecticides. While cost of insecticides increased, assessing pest damage and deciding when it is economical to spray also became very critical in plant protection. Boll/budworm control required changes in the traditional chemical control approach and that came in the form of transgenic varieties.

**Losses in Yield Due to Insects**

| Year | Total Losses Due to Insects % | Losses Due to Boll/Budworms % |
|---|---|---|
| 1993 | 6.86 | 1.56 |
| 1994 | 6.03 | 1.8 |
| 1995 | 11.08 | 5.65 |
| 1996 | 6.61 | 2.37 |
| 1997 | 9.42 | 2.01 |

**Cotton Production Regions and Their Characteristics**

| Cotton Region | States in the Region | Area 1997 % of Total | Production 1997 % of Total | Yield 1997 Kg/ha | Major Boll/Budworms | % Area Under Transgenics in 1997 |
|---|---|---|---|---|---|---|
| West | Arizona, California | 9 | 17 | 1,347 | Pink bollworm, beet armyworm | 18 |
| Southwest | New Mexico, Oklahoma, Texas | 42 | 31 | 606 | Heliothis species, boll weevil | - |
| Delta | Arkansas, Louisiana, Missouri Mississippi, Tennessee | 26 | 31 | 862 | Heliothis spp., boll weevil beet armyworm | 18 |
| Southeast | Alabama, Georgia, Florida North Carolina, South Carolina Virginia | 23 | 22 | 716 | Tobacco budworm, bollworm | 34 |

## Cost of Bt Technology

Bt technology is not free for farmers, as they have to pay for the non-cotton gene that has been inserted into cotton. There is no doubt that it took many years for the private companies to find suitable genes, devise appropriate methods to diffuse them into the cotton genome, test new genotypes and satisfy all regulatory approval requirements before the seed was offered for commercial production. Fees charged to growers are related to the benefits/savings in planting transgenic cotton varieties. It was assumed that if Bt cotton was planted it would significantly reduce the need for spraying insecticides and, accordingly, the fee was related to the savings in insecticide use. Each farmer interested in planting Bt varieties had to sign an agreement with Monsanto Company and one of the important conditions has been not to keep the seed for next year nor pass it on to other cotton growers. Monsanto apparently intends to reap technology benefits for years.

In the absence of competition for the same type of varieties, it was not possible for transgenic cotton growers to negotiate the technology fee. During 1997 farmers could grow BXN varieties or Roundup Ready varieties. However, after 1997 the US Environmental Protection Agency stopped application of bromoxynil on BXN varieties. In March 1998, the Environmental Protection Agency once again granted registration for use of Buctril® on BXN cotton. BXN varieties seed was available for sale in 1998 but no technology fee for BXN gene was charged. The technology fee for various products is not constant. It may go up if stronger genes are identified and inducted into cotton, and it may go down if more companies identify new genes and offer insect resistant varieties with a variety of gene options.

For 1998, Monsanto has maintained the conditions of the agreement but has decided to make it a long duration agreement. Now farmers do not have to sign the agreement every year, but rather it will remain effective until either Monsanto or the concerned grower decides to terminate it. Monsanto has also decided to calculate the technology fee based on the variety planted and the seed drop rate for specific area. The seed drop rate is the number of seeds dropped from the planter to achieve the target plant stand.

**Technology Fee for Transgenic Cotton**

| Transgenic Cotton | 1996 US$/ha | 1997 US$/ha | 1998 US$/ha |
|---|---|---|---|
| Bt cotton | 80 | 80 | 80 |
| BXN cotton | - | 15 | Free |
| Roundup Ready | - | 12 = Stripper varieties<br>20 = Picker varieties | 17 = Stripper varieties<br>22 = Picker varieties |
| Bt + Roundup Ready | - | 101 | 101 |
| Bt + BXN | - | - | 80* |

* BXN gene is free in 1998.

## Economic Benefits

Several studies have evaluated the economic performance of Bt cotton versus non-Bt cotton in the USA. Monsanto, the sole owner of the Bt gene technology, undertook a number of farmers' field studies to assess the economic benefits of Bt cotton. Monsanto collected data from comparable fields across regions in 1995 (from experimental use permits), 1996 and 1997. It was concluded that the combined cost of chemical control operations and the technology fee for Bt cotton could be less or more than insecticides for non-Bt varieties. However, Monsanto found a yield advantage in Bt varieties in the Southeast and Delta Regions. Similar studies in East Texas during 1996 and 1997 showed 33% higher insect control costs for Bt cotton but higher lint yield. Net return benefits were smaller in East Texas. In a widely circulated brochure (004-98-036, 1/98) and a paper presented at the 1998 Beltwide Cotton Conferences (Wier et al 1998), Monsanto has claimed that in the Southeast Region, on the average from 1995-97, Bollgard cotton produced additional returns of US$135/ha.

The Monsanto data showed that the economic advantage of growing Bt cotton does not depend solely on the cost of insect control operations. Insect control cost could be higher in Bt cotton (with most money spent to control insects other than boll/budworms. Bt cotton appears more suitable for the Southeast Region followed by the Delta Region. Economic evaluation of Bt cotton for some states in these two regions is discussed here. Data for other states are not available.

As shown in the table below on losses due to insects, boll/budworm losses were quite high in the USA during 1995/96. 1996/97 was a good year to introduce Bt cotton. Among all cotton producing states in the USA, Alabama

**Performance of Bt vs Non-Bt Cotton 1995-1997**

| | Southeast Region | | Delta Region | | East Texas | |
|---|---|---|---|---|---|---|
| | Bt Cotton | Non-Bt Cotton | Bt Cotton | Non-Bt Cotton | Bt Cotton | Non-Bt Cotton |
| Lint yield (kg/ha) | 1,046 | 918 | 1,081 | 1,030 | 612 | 548 |
| Insect control (US$/ha) | 114 | 66 | 198 | 213 | 162 | 103 |
| Total return (US$/ha) | 1,385 | 1,250 | 1,351 | 1,263 | 710 | 683 |
| Bollgard advantage (US$/ha) | 135 | | 88 | | 27 | |

Note: The cost of insect control in Bollgard includes the technology fee at the rate of US$80/ha. Total return figures are based on US$1.43/kg lint price.

is most affected by tobacco budworm. During 1994 and 1995, tobacco budworm most seriously affected cotton production in Alabama. Farmers there welcomed Bt cotton, and, out of the total cotton area of 227,000 hectares, Bt cotton was planted on 174,000 hectares, 77% of the total area. Consequently, insecticide usage was significantly reduced to the lowest level since synthetic insecticides were introduced. Only 20% of the total transgenic varieties area received any insecticide application and 10% of the area was sprayed only once. The average state yield increased significantly over 1995 to 840 kg/ha. Higher yields brought additional profit to growers (Smith, 1997).

According to Sutton (1998), it was not profitable to grow Bt cotton in Arkansas during 1997. Two similar fields on the same farm at seven locations were selected for comparing cost of production and net return from Bt versus non-Bt cotton varieties. Both fields were cultivated with the objective of maximizing yield and profit to the farmer. The differences between the Bollgard and non-Bt fields were in the area of technology fee, cost of insecticides and their application, growth regulators and second harvest costs. Based on harvested yield and an estimated price of US$1.37/kg of lint, net returns were calculated for Bollgard and conventional varieties.

In most Bt fields, the additional cost of the seed, the necessity of using plant growth regulators, the technology fee and the need to make second pick were responsible for higher cost of production. At three locations, net return was higher in Bt fields but the average of all locations indicated that there is a net loss in planting Bt cotton, partly because of lower yields in Bt fields at some locations. The studies were conducted by the University of Arkansas and reported at the 1998 Beltwide Cotton Conferences in January 1998. According to Kelly Bryant and colleagues, Bt cotton was profitable in 1996, with the difference in net income ranging from a US$39/ha decrease to a US$439/ha increase. During 1997, however, insect pressure was low in Arkansas, which saved on insecticide use in non-Bt varieties and changed the economics of Bt cotton. Bryant et al (1997) concluded that Northern Arkansas, where bollworm pressure is not as high as in Southern Arkansas, might not be economically suitable for Bt cotton.

In principle, if budworms and bollworms are controlled from the very beginning by planting Bt varieties, the plant should enter into the fruiting phase earlier than non-Bt varieties. And, if the plant has bolls from the beginning, it automatically avoids overgrowth and would not require growth regulators. The maturity of the crop should also be earlier and what went wrong in Arkansas during 1997, resulting in late crop maturity and required additional picking, is difficult to explain.

Gibson et al (1997) compared the costs and returns associated with growing Bt cotton and non-Bt cotton in Mississippi for two years. The data included test plot observations and surveys of farmers' fields. Both data sets indicated that Bt cotton had economic advantage over non-Bt cotton during both years. The total cost of production was not different in Bt and non-Bt cottons but higher yields in case of Bt cotton produced significant differences in net return to farmers. During 1995, due to high insect pressure, the cost of insecticides was reduced by one-third in Bt cotton. However, Bt cotton required more expense in the form of fertilizers, fungicide treatments and the technology fee. During 1996, though, the cost of insecticides was lower than in non-Bt cotton, but the additional cost of the technology fee for the Bt gene made insect control in Bt cotton more expensive. Yield in Bt cotton was again higher in 1996 but with a lesser margin and, accordingly, the advantage of growing Bt cotton was not as large as in 1995.

Monsanto's data (Wier et al 1998) suggests the performance of Bt versus non-Bt cotton in Mississippi has been similar to that reported by Gibson. Insect pressure during 1996 was low in Mississippi lowering the insect control costs of non-Bt cotton to the same level of Bt cotton. The data below indicate that in Mississippi, the economic advantage of planting Bt cotton was greatest during 1995.

ReJesus et al (1997) conducted two on-farm trials in South Carolina during 1996 and recommended adopting Bt cotton over non-Bt cotton. Data indicated non-significant differences in yields; however, the cost of insecticides was lower for Bt cotton.

In a separate study (ReJesus et al 1997) in South Carolina, farmers' reasons for planting Bt cotton were surveyed. Potential benefits from savings in insecticide use was the main reason for planting Bt cotton but fewer than 10% of farmers found yield increase the basis for planting Bt cotton. Most farmers did not expect to use pyrethroids, but at least 30% of them had to apply them.

In Georgia, a statewide project was conducted during 1996 to evaluate the economic benefits of growing Bt cotton. Eight farmer field level research experiments were laid out on Bt and non-Bt varieties planted in close proximity and under uniform growing conditions. The results indicated that on average Bt cotton yielded 116 kg/ha more lint over non-Bt varieties at the

**Performance of Bt vs Non-Bt Cotton in Mississippi 1995-1997**

| | 1995 | | 1996 | | 1997 | |
|---|---|---|---|---|---|---|
| | Bt Cotton | Non-Bt Cotton | Bt Cotton | Non-Bt Cotton | Bt Cotton | Non-Bt Cotton |
| Lint yield (kg/ha) | 1,086 | 983 | 1,002 | 950 | 1,103 | 1,009 |
| Insect control (US$/ha) | 176 | 232 | 157 | 144 | 209 | 204 |
| Total return (US$/ha) | 1,380 | 1,176 | 1,279 | 1,218 | 1,372 | 1,239 |
| Bollgard advantage (US$/ha) | 204 | | 61 | | 133 | |

same producer's farm. The number of sprays was reduced by 2.5 sprays/field. Subtracting the technology fee of US$80/ha, on the basis of the 1996 pest situation, it was profitable to shift to Bt cotton in Georgia (Stark, 1997).

## Additional Remarks

*Limited choice* – When Bt cotton was introduced in 1996, only two varieties NuCotn 33$^B$ and NuCotn 35$^B$ were offered for planting. Similarly, during 1998 Bollgard + Roundup Ready genes are available in two varieties, i.e., DP 458 B/RR and DP 688 B/RR, and Bt+BXN gene is available in only one variety, BG 4740. However, over 2 million hectares are seriously affected by tobacco budworm and bollworms in the USA and are considered to be suitable for planting Bt cotton with the current bacterium gene. Farmers are now being offered many Bt and Roundup Ready varieties and hopefully also for stacked gene varieties. If a Bt variety is not suitable for the one area, farmers may suffer some loss in yield and consequently dilute the performance of Bt cotton.

*Impact of Bt cotton* – In the long run Bt cotton will have a significant impact on production practices, particularly insect management. Currently, three possible results from Bt cotton are 1) the Bt toxin will contain some lepidopteran insects and, though the cost of insecticides will not increase, the yield of Bt cotton will be higher than non-Bt varieties; 2) Bt cotton will keep insect pressure below threshold levels and while there may not be a significant increase in yield, Bt cotton will bring significant reduction in insect control costs; and 3) a mix of the first two—there will be some reduction in insect control costs and there will also be some increase in yields. The latter seems most descriptive of the increasing number of experiments being reported.

*Target for yield increase* – None of the currently available commercial genes is supposed to boost yield potential. However, sub-threshold control of insects and weeds would affect yield and is the source of yield increases in Bt and herbicide resistant cottons. There is no evidence to suggest that genes are being explored, which could target physiological changes in the plant to give higher yield.

*Abnormal behavior* – Both Bt and Roundup Ready cottons showed unexpected reactions to the growing conditions in some areas during 1996 and 1997 respectively. Though so called ineffective control of worms by Bt cotton and malformation of leaves and shedding in Roundup Ready were small scale problems, the new gene's existence in the cotton genome may react undesirably to environmental conditions, particularly if they have changed from the period when transgenic cotton was tested.

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