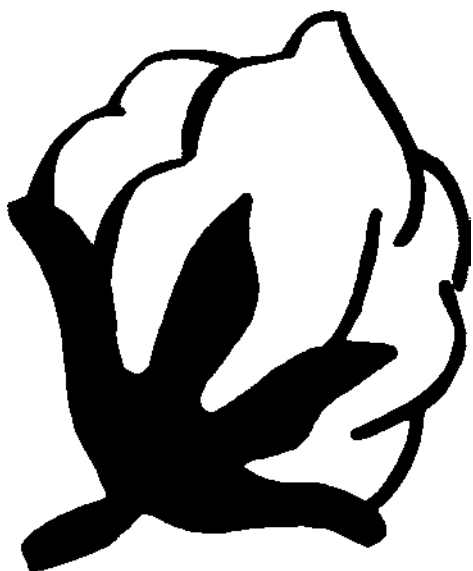




# **THE ICAC RECORDER**

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International  
Cotton  
Advisory  
Committee

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Technical  
Information Section

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Update on Cotton  
Production Research

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## Introduction

The development of transgenic Bt cotton provides a new and unique defense against many major insects that directly affect flowers, buds and bolls. The Bt protein in the plant affects all insects that have specific receptors in the mid-gut, and the action is quick and as effective as insecticides. Researchers in countries where insecticides have been used for years have seen that insects are developing resistance or have already developed resistance to a group of insecticides. The experience with insecticides, particularly pyrethroids, has taught a good lesson that has helped to devise strategies for avoiding the development of resistance to the Bt toxin. Planting of a refuge crop was strictly adhered to in all countries that adopted Bt cotton.

The second strategy, which has been promoted since the introduction of commercial Bt cotton, has been the utilization of alternate protein toxins from the same soil bacterium or from other sources. 2003/04 will be the first year that the second generation of Bt genes called Bollgard II, with the potential to control more lepidopterans, will be available for commercial use in Australia and the USA. The Cry2Ab gene in Bollgard II provides equally good control of fall armyworm *Spodoptera frugiperda*, beet armyworm *Spodoptera exigua*, cabbage looper *Trichoplusia ni*, and soybean looper *Pseudoplusia includens*, in addition to bollworms and budworms already controlled by Bollgard. The Cry2Ab gene has been inducted in the existing Bt varieties that have the protein Cry1Ac. Trials conducted in the USA for the last four years indicate that Bollgard II varieties gave higher yields compared to Bollgard and sprayed non-Bt varieties. There is no negative interaction between the two toxins. The Bollgard and Bollgard II technologies will continue to be available for many years, but Bollgard II will ultimately replace Bollgard. Stacked-gene varieties having the herbicide resistance gene with Bollgard II will be available soon. Bollgard II, and its comparative performance against Bollgard (Ingard in Australia, and commonly called Bt cotton in other countries), is discussed in detail in the first article in this issue of *THE ICAC RECORDER*.

The Technical Information Section of the ICAC has written extensively about production of organic cotton. Organic cotton production started in Turkey in 1989/90. Production reached the 15,000-ton mark for the first time in 1999/00 due to huge production increases in Turkey. The quantity of organic cotton produced in the USA has declined. It is estimated that the total organic cotton produced in the world may be over 15,000 tons during the last few years. Nineteen countries were producing organic cotton by mid-1990, and it is believed that at least seven of them have already stopped. The elimination of insecticides and other toxic chemicals is highly desirable and must be encouraged. It is believed that there is a demand for organic cotton but a number of limitations have discouraged its production. The second article is focused on these limitations. The article also provides guidelines on how organic production could be encouraged and made more successful.

Short Notes is also a part of this issue wherein the performance of commercial Bt hybrids in India is reported. According to Monsanto's data from five states, farmers in India increased their income by an average of US\$377/ha by planting Bt hybrids. A brief note on the economic impact of Bt cotton indicates that the world average price has been lower by 2.6 cents/kg of lint due to the planting of Bt cotton. International prices would have been lower by 1.5 cents/kg of lint if Bt cotton had been planted only in the USA. The planting of Bt cotton in the rest of the world lowered average prices by an additional 1.1 cents/kg of lint.

The IV Brazilian Cotton Congress will be held in Goiânia, Goiás, from September 15-18, 2003. The theme of the congress is "Cotton: A Market in Evolution." The congress is held every two years. The first congress was held in 1997 and was limited to discussing irrigated cotton, but its scope has broadened since. The III Congress, held in August 2001, was attended by about 2,000 researchers from many countries in the region and the USA. The IV Congress will have conferences, workshops and short courses on all aspects of production, from cotton as family agriculture to agricultural politics for cotton cul-

tivation, the textile industry and the mechanism of the futures market. More information on the congress can be obtained from:

IV Brazilian Cotton Congress  
Av. 87 No. 662 - Setor Sul  
Goiânia, Goiás 74093-300, Brazil  
Tel: 55-62-5410163  
Email: 4cba@cultura.com.br  
Website: <http://www.4cba.com.br>

The World Cotton Research Conference-3 was held in Cape Town, South Africa, from March 9-13, 2003, hosted by the

ARC-Institute for Industrial Crops and sponsored by CIRAD, FAO, ICAC, Cotton South Africa, the Agricultural Research Council of South Africa, and many private companies. Over 300 researchers from 38 countries, in addition to representatives of several international organizations attended the conference. Brazil, Turkey and the USA offered to host the World Cotton Research Conference-4 in 2007. The International Committee of the WCRC-3 will consider proposals from the three countries in its meeting in Poland during the ICAC plenary meeting, and will take a decision that will be announced in *THE ICAC RECORDER*.

## Bollgard II: A New Generation of Bt Genes Commercialized

The first transgenic cotton resistant to lepidoteran pests was approved for commercial utilization in Australia and the USA in 1996/97. The gene has proved its worth in a number of countries across continents, but controversy still continues regarding its environmental safety. Even though some countries are convinced that the technology is safe, they are not willing to adopt it because of potential trade implications with importing countries that are not yet convinced that the technology is risk-free. Thus, efforts to promote and adopt transgenic cotton varieties are continuing, and much area is already under commercial production. It is expected that the greatest increase in area in 2003/04 will be in China (Mainland) and India. Colombia is expected to become a transgenic cotton-growing country in 2003/04, and a number of other countries will intensify their efforts in the field of biotechnology to get closer to the commercialization stage.

Eight countries have already adopted transgenic varieties resistant to lepidopterans, herbicides or both. The Cry1Ac toxin has eradicated bollworms and budworms from cotton fields. 2003/04 will be the first year that a new protein, Cry2Ab in Bollgard II varieties, will join the fight against bollworms and budworms in Australia and the USA. Monsanto is the sole owner of the Bollgard II technology. On December 23, 2002, the Monsanto Company announced that they had received full U.S. regulatory clearance for its Bollgard II insect-protected cotton technology, clearing the way for large-scale use of the second Bt gene along with the first Bt gene introduced in 1996/97. In Australia, the Office of the Gene Technology Regulator has already given approval for limited commercial release of Bollgard II, after a comprehensive scientific assessment and a public consultation process. While in the USA approval includes the whole country, in Australia it extends only to the established cotton growing areas of New South Wales and Queensland, and a new cotton growing area in the north not to exceed 800 hectares. Other countries are still experimenting but are not expected to adopt Bollgard II in 2003/04. Argentina

has proved more willing to adopt biotechnology in the past and could accept Bollgard II in a year or two. No country has adopted the Bollgard II technology without first using Bollgard.

### Benefits of Bollgard II

The U.S. Department of Agriculture (USDA) and the Food and Drug Administration (FDA) have already confirmed the food, feed and environmental safety of Bollgard II, which uses the same soil bacterium found in Bollgard, but in a different gene. The primary objective remains the same-control of target insects that damage bolls. However, Bollgard II has additional advantages, some of which are long-lasting and some short-term.

- The basic objective of finding the second Bt gene is to delay the development of resistance. Target lepidopterans, if fed on the Cry1Ac Bt toxin for years, will develop resistance. Bollgard II has two Bt genes at the same time, because insects can develop resistance to one gene faster than to two genes working in the same genotype.
- The Cry proteins are not equally effective against all bollworms. The Cry1Ac gene in Bollgard offers maximum resistance to the tobacco budworm *Heliothis virescens* and to the American bollworm *Helicoverpa armigera*, but comparatively less resistance to other lepidoterans. The second objective of inserting the Cry2Ab gene is to extend the spectrum of bollworms and budworms controlled by Cry proteins. The Cry2Ab gene in Bollgard II provides equally good control of fall armyworm *Spodoptera frugiperda*, beet armyworm *Spodoptera exigua*, cabbage looper *Trichoplusia ni*, and soybean looper *Pseudoplusia includens*, in addition to bollworms and budworms already controlled by Bollgard.
- Some bollworms and budworms survive on Bollgard varieties, particularly towards the end of the fruit formation stage. The phenomenon, which occurs due to a low amount of Cry1Ac toxin in the flowering stage, is responsible for some

loss in yield. It is not recommended to use insecticides at this point to control bollworm and budworms surviving on Bollgard varieties because of the cost benefit ratio. Cry1Ac levels are usually expressed 1 to 3 parts per million, while Cry2Ab in Bollgard II varieties is expressed from 7 to 19 parts per million. The higher dose of toxins in the form of Bollgard II will save the plant from late season losses.

## Variability in the Cry1Ac Quantity

The amount of Cry1Ac, which is different in different parts of the plant, has much to do with the ability of the plant to resist target pests. Studies have been undertaken by Greenplate et al (2000) and many others to investigate if the amount of Cry1Ac protein remains the same in all plant parts throughout the growing season. They also looked into the effect of location of the quantity of the toxin in the same variety. An average of twelve trials conducted in nine states in the USA revealed that environmental sites, sampling time and tissue type contribute significantly to the variability among Cry1Ac levels in the same variety. Terminal parts were found to have more Cry1Ac compared to squares and bolls.

**Cry1Ac in Plant Tissues**

| Tissue   | $\mu\text{g dry weight}$ |
|----------|--------------------------|
| Terminal | 22.3                     |
| Square   | 14.1                     |
| Boll     | 17.1                     |

Plants were found to have a maximum Cry1Ac expression four weeks post-pinhead-square stage. Mean Cry1Ac concentration within specific tissues, although variable from one sampling time to another, showed no specific trend over time to either increase or decrease. The study suggested that similar tissues of same physiological age might express Cry1Ac at levels around tissue/age-specific mean throughout the fruiting cycle. The environmental effect was found to be significant in the expression of Cry1Ac. Variation among site locations was much greater compared to variation among tissues and the age of the tissue. Variation among the twelve trials ranged from 7.4 micrograms per gram ( $\mu\text{g}$ ) dry weight to 31.5  $\mu\text{g}$  dry weight.

## The Australian Experience with Bollgard II

Studies were conducted on Bollgard II in Australia in 2002/03. The amount of toxin expressed in fruit forms and other parts of the plant was evaluated to assess additional effects of the second Bt gene. Trials revealed that Bollgard II genotypes had a two to three times higher quantity of the toxin in the terminal leaves than Bollgard. Bollgard genotypes on average expressed the Cry1Ac toxin at 27  $\mu\text{g}$  of dry weight, compared with 150  $\mu\text{g}$  in Bollgard II.

Researchers also evaluated the expression of toxin in the flower bud between the two types of transgenic cottons. It is more important to have a higher protein expression in the flowering parts than in leaves because target insects attack flowering parts.

It is known that Bollgard varieties have higher toxin levels in leaves than in squares. The Australian data revealed that on average Bollgard varieties produced half the amount of protein in squares versus leaves (27 versus 50 micrograms). On the contrary, Bollgard II genotypes produced more protein in squares than in leaves. The first position retention in Bollgard II varieties also improved over Bollgard.

No genetically engineered products are approved for sale as food in Australia and New Zealand unless they undergo a safety assessment by Food Standards Australia New Zealand. Approval will only be given if the genetically engineered food is found to be as safe and wholesome for human consumption as its conventionally-produced counterpart. After assessing products derived from Bollgard II, Food Standards Australia New Zealand found them safe for human consumption and approved the sale of oil and linters from Bollgard II cotton containing genes that confer insect protection to the cotton plant. Australia also decided that food products containing oil and linters derived from Bollgard II cotton would be exempt from GM labeling requirements, unless novel DNA and/or protein are found in the final food.

## Bollgard II Trials in the USA

Bollgard II has been evaluated extensively in the USA for four years. The comparison included Bollgard II with Bollgard, sprayed non-Bt and unsprayed non-Bt varieties. The trials were conducted at Louisiana State University during 1999/00 and 2000/01. The sprayed plots received weekly applications (early July through mid-August) of an insecticide for worm control; the other plots received no insecticide applications for worm control. All other insect pests were controlled on an as-needed basis and applications were made through the entire trial. Insect damage was assessed weekly from early July through mid-August.

The strongest indication of the Bollgard II effect was seen in the form of significantly less damage to squares. If there is minor damage to squares more bolls are formed resulting in higher yields. Yield data revealed that during both years, Bollgard II gave a higher yield over Bollgard and other entries in the trials. The data below indicates that even if Bollgard or Bollgard II genes are used for protection from fruit loss, some loss in yield still occurs in Bollgard though the loss is much lower. Non-Bt varieties sprayed with insecticides as needed suffered as much as 6.2% square damage. Bollworm damage adds to square damage, as the most damaged squares will not even become bolls.

**Square Damage in USA Trials in 2000/01**

|                  |      |
|------------------|------|
| Bollgard II      | 0.7% |
| Bollgard         | 1.7% |
| Sprayed non-Bt   | 6.2% |
| Unsprayed non-Bt | >15% |

Reports indicate that the cotton flower attracts bollworms more than squares, flower buds or bolls. According to Gore et al (2001), during 1996/97, the first year of Bollgard cotton in the

USA, a large number of bollworm *Helicoverpa zea* larvae was found feeding on white flowers in many Bollgard fields across the United States. Little information is available on why the bollworm larvae are more commonly observed on white flowers, but the possible explanation could be related to the amount of toxin in the white flower compared to other parts. The nutritional value of the flower could also attract more bollworm larvae. Gore et al (2001) compared the conventional form with Bollgard and Bollgard II forms of DP 50. The bollworm larvae were reared in the laboratory. Various flower parts were harvested from the field and the bollworm larvae were allowed to feed on flower parts in small petri dishes. Five larvae were released in each 9.0 cm petri dish. Larval mortality was measured after 24, 48 and 72 hours of larvae release.

The table below indicates that bollworm survival varied among floral parts after 24, 48 and 72 hours of larvae release into the petri dishes. Bollworm survival was minimal on bracts, followed by squares and petals. Square anthers and flower anthers showed higher survival after 24, 48 and 72 hours of bollworm larvae release into the petri dishes. The same trend was seen in all three varieties. Comparison among varieties revealed that the Bollgard II gene let the smallest number of bollworm larvae to survive, particularly after 48 and 72 hours of larvae release. After 72 hours of release only 6% of the larvae survived on Bollgard II bracts compared to 63% and 50% survival on flower anthers and squares, respectively, at the same time interval. The survival rate decreased from 79.2% to 63.8% and 32.6% in conventional, Bollgard and Bollgard II, respectively, after 72 hours of the release of bollworm larvae. Whatever the reason, the results clearly showed that bollworm lar-

vae prefer specific feeding sites on the cotton plant, the highest preference being flower anthers followed by square anthers. The biochemical factors associated with flower bracts made them least preferred. When utilizing the Bt gene technology, it is important to enhance the concentration of the toxin in anthers for effective bollworm control. The same approach seems to have been followed in Bollgard II technology.

Transgenic cotton can be viewed as useful from different perspectives but its success depends on growing conditions and the benefit could be less environmental pollution. Allen et al (2000) studied the effectiveness of Bollgard II cotton varieties against foliage and fruit feeding caterpillars in Arkansas. They reported that according to a paper presented by Michael R. Williams at the 2000 Beltwide Cotton Conferences of the National Cotton Council of America, cotton losses due to caterpillar pests did not decline in the United States since the release of Bt varieties from 1996 to 1999. On average, losses due to caterpillars remained around 4.5% from 1996 to 1999, almost the same as prior to the introduction of Bt cotton. In their own studies, Allen et al (2000) showed that Bollgard II varieties exhibited a far lower number of beet armyworm, tobacco budworm, cabbage looper and soybean looper than Bollgard and non-Bt varieties. Thus, the indications are that Bollgard II technology could reduce caterpillar losses in the USA.

Bollgard II has been tested not only on experimental farms but also under field conditions to obtain realistic expectations about the potential fitness of this new technology in transgenic cotton. Bachelier and Mott (2003) undertook studies for three years, from 2000 to 2002, concluding that Bollgard II varieties would seldom require insecticide treatments for caterpillar control in

North Carolina, and noted that Bollgard II fields had a higher stink bug population because they were sprayed on average less than once a season.

Many studies have shown that the quantity of toxin from the Bollgard Cry1Ac gene declines toward the end of plant maturity and the end of the growing season. At these stages, if a large number of bolls are yet vulnerable to caterpillar attack, insecticide applications may be required, according to work done by Gore et al (2001) and mentioned above. The same conclusion has been made by Akin et al (2003) in their studies undertaken in Mississippi. Akin and his colleagues collected bolls from the first and second positions starting from the seventh node to the nineteenth node in Bollgard and Bollgard II varieties. Using the enzyme-linked immunosorbent assay (ELISA) technique, they measured the Bt toxin separately as Cry1Ac and Cry2Ab. The data showed that Cry1Ac

**Bollworm Survival on Conventional, Bollgard and Bollgard II Flower Parts**

| Hours | Floral Structure | Varieties               |                      |                            | Average |
|-------|------------------|-------------------------|----------------------|----------------------------|---------|
|       |                  | DP 50<br>(Conventional) | DP 50B<br>(Bollgard) | DP 50 BII<br>(Bollgard II) |         |
| 24    | Bracts           | 83                      | 80                   | 89                         | 84.0    |
|       | Petals           | 98                      | 100                  | 99                         | 99.0    |
|       | Flower anthers   | 98                      | 100                  | 99                         | 99.0    |
|       | Square anthers   | 98                      | 100                  | 100                        | 99.3    |
|       | Squares          | 85                      | 96                   | 97                         | 92.7    |
|       | Average          | 92                      | 95                   | 97                         |         |
| 48    | Bracts           | 67                      | 57                   | 29                         | 51.0    |
|       | Petals           | 95                      | 90                   | 81                         | 88.7    |
|       | Flower anthers   | 98                      | 98                   | 88                         | 94.7    |
|       | Square anthers   | 98                      | 97                   | 72                         | 89.0    |
|       | Squares          | 80                      | 77                   | 38                         | 65.0    |
|       | Average          | 88                      | 84                   | 62                         |         |
| 72    | Bracts           | 48                      | 18                   | 6                          | 24.0    |
|       | Petals           | 81                      | 67                   | 36                         | 61.3    |
|       | Flower anthers   | 95                      | 93                   | 63                         | 83.7    |
|       | Square anthers   | 97                      | 92                   | 50                         | 79.7    |
|       | Squares          | 75                      | 49                   | 8                          | 44.0    |
|       | Average          | 79                      | 64                   | 33                         |         |

protein was highest in the first and second position bolls on the ninth node. The first and second position bolls on the fifth node contained almost 5 ppm of Cry1Ac compared to around 7 ppm at the ninth node. The concentration of Cry1Ac protein started declining after the ninth node and came down to about 4 ppm on the seventeenth node. The concentration was slightly higher on all nodes in the first position bolls compared to the second position bolls on the same nodes. A similar trend was noted for Cry2Ac on nodes from seventh to seventeenth. The ninth node had the maximum concentration, over 7 ppm, which dropped to 5 ppm on the first position bolls and 4 ppm in the second position bolls on the seventeenth node. The work indicated that the individual concentration of Cry1Ac and Cry2Ab would decline in the dual toxin Bollgard II varieties. However, the concentration of Bt toxins together in Bollgard II varieties would be double the concentration in Bollgard varieties. It was concluded that bolls of the same phenological age would have the same concentration of toxins in Bollgard II varieties. Such a conclusion confirms that environmental factors will continue to be important in the expression of toxins in cotton. But the effect of the decline in toxin expression on the survival of target pests needs to be seen.

The additive action of the two Bt genes has been shown by Catchot and Mullins (2003) in terms of damage to squares and bolls and lint yields in system trials. They tested a Bollgard II variety against its isogenic Bollgard line and against an isogenic conventional variety at many locations under different treatments, which they called system treatments. The unsprayed trials were not treated at all for lepidopteran insects throughout the growing season. However, when non-lepidopteran insects reached threshold levels, the entire experimental area was sprayed with an insecticidal product that had no or very little lepidopteran activity. In the system trials, each variety was managed independently according to the threshold of the lepidopterans at various stages of development. But, as in the case of unsprayed trials, the entire area was sprayed with the appropriate insecticides with minimum or no activity toward lepidopterans. The data for seasonal mean damage to squares and bolls and lint yield is shown in the table.

According to Catchot and Mullins (2003), the average of all unsprayed trials (not sprayed against lepidopterans) they conducted in the mid-south and east Texas in the USA showed 0.52% and 0.15% damage to squares and bolls in Bollgard II compared to 2.47% and 2.0% in the case of Bollgard, and 11.24% and 8.66% in the case of non-Bt isogenic lines. Bollgard II protection against lepidopterans gave a higher yield by 317 kg/ha over non-Bt, and 53 kg/ha over the Bollgard line. A similar trend was seen in the system trials, but the margin in yield over non-Bt cotton declined due to non-Bt protection against

**Effect of Bt Genes Under Sprayed and Unsprayed Conditions**

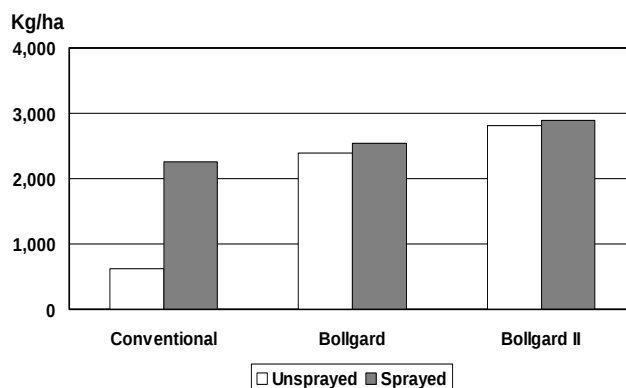
| Insecticide Regime | Genotype    | No. of Bollworm Adults/ha (%) | No. of Bolls Damaged/ha (%) | Lint Yield (kg/ha) |
|--------------------|-------------|-------------------------------|-----------------------------|--------------------|
| Unsprayed trials   | Non-Bt      | 11.24                         | 8.66                        | 902                |
|                    | Bollgard    | 2.47                          | 2.00                        | 1,137              |
|                    | Bollgard II | 0.52                          | 0.15                        | 1,185              |
| System trials      | Non-Bt      | 7.31                          | 8.16                        | 833                |
|                    | Bollgard    | 1.55                          | 3.25                        | 941                |
|                    | Bollgard II | 0.79                          | 0.60                        | 1,001              |
| Average            | Non-Bt      | 9.37                          | 7.93                        | 870                |
|                    | Bollgard    | 1.95                          | 2.40                        | 1,047              |
|                    | Bollgard II | 0.53                          | 0.33                        | 1,100              |

lepidopterans. Bollgard II exhibited a higher yield over Bollgard and non-Bt recurrent parents.

A report presented at the 2002 Beltwide Cotton Conferences by D. S. Brickle and A. L. Catchot of Monsanto, about a similar trial conducted in 2001, also showed that Bollgard II gave higher yields and provided more effective control against bollworms, beet armyworm and soybean loopers than Bollgard. Bollgard II varieties left untreated for lepidopteran pests averaged 103 kg/ha lint more than Bollgard varieties left untreated for lepidopterans. The data collected on Bollgard II, Bollgard and conventional genotypes under unsprayed conditions for beet armyworm larvae showed 0.1, 9.6 and 10.2 larvae per meter of row. Similar data for soybean loopers showed 0.4, 8.0 and 10.7 larvae per meter of row respectively on Bollgard II, Bollgard and conventional varieties.

Trial data on yield comparisons among non-Bt, Bollgard and Bollgard II varieties is always variable, mainly because of the pest complex. Assuming that there was absolutely no pest attack and the three types of varieties, non-Bt, Bollgard and Bollgard II, were grown under similar agronomic conditions, there would be no difference in yield. But the higher the pressure from target pests, the more significant the difference in yield. The difference in yield could also be reflected in terms

**Lint Yield in Non-Bt, BG and BG II**



of insecticide sprays required to control the target boll and budworms based on their thresholds. Under such a situation, the yield difference between the unsprayed conventional and sprayed conventional varieties is supposed to be very high. A similar trend could be found between a sprayed conventional variety, unsprayed Bollgard and unsprayed Bollgard II variety. The data given in the chart (Sherrick et al 2003) is limited to conditions in the U.S. southeast region, but it clearly indicates the impact of a single Bt gene toxin and the combined effect of two proteins under sprayed and unsprayed conditions versus a conventional variety under sprayed and unsprayed conditions.

## Beet Armyworm

One of the advantages of the Bollgard II gene is resistance to beet armyworm *Spodoptera exigua* that primarily feeds on plant leaves. Previous studies on Bt varieties have shown variability in the expression of toxin in various plant parts. The same plant parts contained variable quantities of the toxin at various stages of development. The toxin expression declines in the terminal leaves throughout the season as well as within individual leaves as they age. So, the fear is that target insects will encounter low protein levels as they move downward on the plant and increase their chances of survival for a little longer, if not escape all together. During this period, damage will continue. Sparks and Norman (2002) studied the survival of beet armyworm larvae on young and old leaves containing the Bt toxin. They planted three varieties in Texas—DPL 5415 (no Bt gene), NuCotton 33B (Bollgard gene) and NuCotton 33BII (Bollgard II gene). The studies were conducted in the laboratory on leaf samples collected in the field on the 86-day old crop from four different places on the plant, the third, sixth, ninth and twelfth leaf from the main terminal. Bioassay studies were done using one-day-old larvae. Nineteen days later, similar samples were collected and bioassays were done using five-day-old larvae. Leaf samples were collected from five different plants in each of the four replications per variety using lab-reared colonies of beet armyworm. Leaves were cut in 7/8 inch leaf disks and placed in plastic cups. One beet armyworm larva was placed on the leaf disk and mortality was checked every two days. At each check, the surviving larvae were provided with a fresh leaf sample. Data were recorded for ten days on the one-day old larvae and for eight days on the five-day old larvae. The surviving larvae were weighed for their ability to tolerate the toxin doses.

The results revealed that two days after the larvae were released on the leaves, mortality was low in each test (one-day and five-day-old larvae) and generally remained so for the younger leaves in DPL 5415. It confirmed that the mortality at later stages is the result of the Bt toxin rather than the handling and disease

effects on the colonies. The data revealed that the presence or absence and type of Cry protein and leaf age had a significant impact on mortality and weight of the larvae after ten days of feeding. The average data across leaf ages showed that 88.3% of the larvae died after ten days when the one-day-old larvae were released on Bollgard II leaves compared to 20.4% on Bollgard leaves, and only 12.9% on non-Bt variety. The five-day-old larvae could tolerate a higher dose of Cry2Ab toxin, and only 46.3% of the larvae died after eight days on Bollgard II leaves compared to less than 1% mortality on the Bollgard and non-Bt varieties. The Bollgard II gene not only killed a higher percentage of larvae but also the weight of the surviving larvae was much lower compared to the other varieties. The average data for the three varieties showed that larvae surviving on the non-Bt variety had the greatest weight. The one-day-old larvae showed minimum mortality on the third position leaves and a linear mortality increase with the increase in the age of the leaves. Similar results were achieved on the five-day-old larvae where mortality increased from 3.3% on the third position leaves to 26.7% on the twelfth position leaves after eight days of feeding. The weight of the larvae surviving after ten days and eight days decreased with the increase in the age of the leaf.

The table reveals that variety and leaf age interaction effects are significant whether the larva is a day old or five days old. The one-day-old larvae presented some mortality even in the absence of the toxin, but all the five-day-old beet armyworm larvae survived when they were fed for eight days on a non-Bt variety as well as on a Bt variety carrying only the Cry1Ac gene. 76.6% of beet armyworm larvae died after eight days on Bollgard II leaves. Only 10% of the five-day-old larvae feeding on the third position leaves was killed by Cry2Ab (Bollgard II), indicating that terminal growth is the most likely location where beet armyworm larvae could survive.

**Effect of Leaf Age and Variety on Mortality of Beet Armyworm**

| Variety         | Leaves<br>from Terminal | Mortality (%)                           |                                         |
|-----------------|-------------------------|-----------------------------------------|-----------------------------------------|
|                 |                         | One-day Old Larvae<br>(10 days feeding) | Five-day Old Larvae<br>(8 days feeding) |
| DPL 5415        | 3                       | 1.7                                     | 0.0                                     |
|                 | 6                       | 13.3                                    | 0.0                                     |
|                 | 9                       | 1.7                                     | 0.0                                     |
|                 | 12                      | 35.0                                    | 1.7                                     |
| NuCotton 33B    | 3                       | 18.3                                    | 0.0                                     |
|                 | 6                       | 0.0                                     | 0.0                                     |
|                 | 9                       | 35.0                                    | 0.0                                     |
|                 | 12                      | 28.3                                    | 1.7                                     |
| NuCotton 33B II | 3                       | 65.0                                    | 10.0                                    |
|                 | 6                       | 88.3                                    | 26.7                                    |
|                 | 9                       | 100.0                                   | 71.7                                    |
|                 | 12                      | 100.0                                   | 76.7                                    |

Harris et al (2002) conducted field studies for three years, starting in 1999, on Bollgard and Bollgard II against bollworms and other insects under sprayed and unsprayed conditions in the state of Mississippi, and measured lint damage caused by various pests. Sprayed plots received two caterpillar treatments while unsprayed fields received five treatments for the damaged-plant bug. Data on feeding damage by beet armyworm larvae on leaves per 9.14 meters were recoded at three stages. At each stage the non-Bt variety and the Bt variety showed damage ranging from 0.8-5.8 under sprayed conditions and 1.0-4.5 under unsprayed conditions. The extent of the damage was almost the same on the Bollgard variety under sprayed and unsprayed conditions. The Bollgard II variety did not show any damage due to beet armyworm at any stage when fields were checked three times during the season. The feeding damage by beet armyworm larvae on leaves per 9.14 meters was zero.

Sivasupramaniam et al (2003) conducted similar studies and compared the effect of feeding on various parts of the plant on bollworm weight. Vegetative and flower parts were included as feeding material and the varieties used were three isolines, DP 50, DP 50B and DP 50BII. Various plant tissues as given in the table below were freeze-dried, finely powdered and utilized in all assays. ELISA and tobacco budworm quantitative bioassays were conducted to study the expression profile. Activity against bollworm larvae was ascertained using a diet-based assay, where the tissue in agar was overlaid on diet (2% tissue in 0.2% agar), and infested with the first instar larvae. Data were recorded seven days after infestation.

The ELISA and quantitative bioassay data showed that all tissues under investigation expressed Cry1Ac alone and in combination with Cry2Ab in all parts of the plant. However, as discussed earlier in this paper, the protein quantity was different in different parts of the plant. The results from the quantitative bioassay analysis showed that expression profile of proteins in nine different parts of the plant was similar in both types of transgenics. Bollgard had the highest amount of Cry1Ac in the terminal leaf followed by petals and anthers. Bollgard II also had the highest quantity of Cry2Ab in the terminal leaves. But squares were also found to have a high quantity of Cry2Ab.

#### Mean Weight of the Surviving Bollworm Larvae (g)

| Plant Part    | DP 50 | DP 50B | DP 50BII |
|---------------|-------|--------|----------|
| Large leaf    | 77.3  | 27.8   | 6.1      |
| Terminal leaf | 63.5  | 19.0   | 5.7      |
| Square        | 48.8  | 12.6   | 3.4      |
| Bract         | 80.0  | 28.8   | 10.5     |
| Calyx         | 83.8  | 25.5   | 12.5     |
| Petal         | 56.2  | 16.7   | 5.4      |
| Anthers       | 39.3  | 14.7   | 5.6      |
| Ovule         | 25.0  | 8.9    | 3.2      |
| Small boll    | 26.5  | 11.1   | 3.6      |
| Average       | 55.6  | 18.3   | 6.2      |

The ELISA analysis showed the highest quantity of Cry1Ac in the terminal leaves. However, the ELISA test showed the highest quantity of Cry2Ab in ovules, at least double that in many other parts and ten times more than in the calyx. The weight of bollworms surviving on these plant parts varied. In general, DP 50 produced the most healthy bollworm larvae followed by Bollgard. Bollworm larvae surviving on the Bollgard II variety had the least weight. None of the larvae surviving on Bollgard II lived beyond the second larval stage or seven days post infestation.

## Interaction Between Two Toxins

Cry1Ac and Cry2Ab are protein toxins that can interact and affect the performance of one or both toxins. Monsanto has already undertaken studies on this subject and it was reported by Greenplate et al (2002) that there is no interaction between the two Cry proteins. They designed a study to quantify the bio-efficacy of Cry1Ac/Cry2Ab (Bollgard II) cotton and compared it with Cry1Ac (Bollgard) in the tobacco budworm *Heliothis virescens* bioassay. Three isolines of a variety having Cry1Ac only, Cry2Ab only and Cry1Ac+Cry2Ab were used to examine the relative contribution of each toxin to the total efficacy of Bollgard II, in addition to studying the nature of the interaction (synergistic/antagonistic or additive) of the individual toxins in the 2-gene cotton. Purified Cry1Ac was used as a standard for comparison.

The data for the quantity of Cry proteins in three different isolines is given in the table. The Bollgard II line contained a simple additive quantity of Cry1Ac and Cry2Ab as measured individually in two different isolines. The results showed that the addition of Cry2Ab to Cry1Ac in cotton provided a highly significant and uniform increase in lepidopteran bioactivity. The lepidopteran activity in the *H. virescens*

#### Cry1Ac and Cry2Ab Proteins in Two Isolines (µg dry weight)

| Plant Part    | ELISA Analysis |             | Quantitative Bioassay |             |
|---------------|----------------|-------------|-----------------------|-------------|
|               | Bollgard       | Bollgard II | Bollgard              | Bollgard II |
| Large leaf    | 0.9            | 419         | 21.3                  | 200         |
| Terminal leaf | 8.3            | 372         | 36.1                  | 263         |
| Square        | 4.8            | 642         | 21.6                  | 221         |
| Bract         | 0.6            | 302         | 10.4                  | 110         |
| Calyx         | 1.3            | 137         | 8.9                   | 43          |
| Petal         | 5.6            | 380         | 34.5                  | 90          |
| Anthers       | 5.8            | 583         | 24.5                  | 68          |
| Ovule         | 4.5            | 1243        | 22.3                  | 170         |
| Small boll    | 5.0            | 792         | 22.6                  | 198         |
| Average       | 4.1            | 541.1       | 22.5                  | 151         |

quantitative assay was 3-6 times higher in the 2-gene cotton. Using the enzyme-linked immunosorbent assay test on every lyophilized plant sample in the study, it was confirmed that neither toxin was influenced by the presence of the other. ELISA results confirmed that the level of each toxin in the 2-gene isolate is identical to the level found in its single-gene isolate.

**Quantity of Cry Proteins in Three Isolines  
(mg/g of dry weight)**

| Isolines | Cry1Ac | Cry2Ab |
|----------|--------|--------|
| Cry1Ac   | 7.2    | 0.0    |
| 2-gene   | 7.0    | 412.0  |
| Cry2Ab   | 0.0    | 417.7  |

Jackson et al (2003) studied the *Helicoverpa zea* bollworm population production and associated damage to bolls in Bollgard and Bollgard II cotton versus the conventional variety under sprayed and unsprayed conditions. Trials were conducted at three locations in North Carolina and the results were presented at the 2003 Beltwide Cotton Conferences. DP50 was grown in pure form, in Bollgard and Bollgard II forms at all locations. Insecticide treatments included in-furrow applications of aldicarb (Temik) for the control of early season sucking insects, a mid-season application of an insecticide for the control of plant bugs and stink bugs, and two applications of a suitable insecticide for supplemental bollworm control. Other agronomic operations were carried out as recommended in the area.

According to the authors, the 2002/03 season in North Carolina was characterized by high bollworm pressure. Data were recorded in smaller plots for bollworm larvae, bollworm pupae, bollworm adult and damaged bolls; the data were converted into a per-hectare basis. They found that, on average, 400,000 bolls per hectare were affected by bollworm under sprayed DP50 compared to 190,650 bolls in Bollgard DP50 and only 23,315 bolls in Bollgard II DP50. Bollworm damage under unsprayed conditions was reduced in Bollgard II by 172 times over the non-Bt gene of the same variety, and by 45 times over the Bollgard variety. Insecticide treatments drastically reduced the number of bolls damaged by bollworm to 142,814; 35,530; and 2,464 bolls/ha in DP50, Bollgard DP50 and Bollgard II DP50 respectively.

## Prospects for Bollgard II

In the USA, growers have already reached the potential area for transgenic cotton by planting 77% of the total cotton area under transgenic varieties in 2002/03. However, only 40% of the total area under transgenic varieties had the Cry1Ac gene, 3% in pure form and 37% in stacked form with the Roundup ready herbicide resistant gene. The recommended adherence to the planting of a refuge crop will continue for Bollgard II and for Bollgard. The main purpose of the refuge crop is to delay the development of resistance to the Bt toxin. It is still feared that target insects could develop resistance to both toxins at the same time. Thus, in the USA, it is anticipated that the

approval of Bollgard II technology could bring some increase in area planted to Bt genes. The main reason for the increase in area could be the increase in the spectrum of insects controlled by Bollgard II over Bollgard. Because a larger area will attract a larger number of Bollgard plus Bollgard II target pests, more growers will be interested to grow Bollgard II. The cotton area that will benefit the most in the USA will be the one affected by loopers and fall armyworms, such as south Georgia and Mississippi.

Bollgard II will be introduced to farmers through Delta and Pine Land Company and Stoneville Pedigree Seed Company in the USA and will be in the commercial scale stage, called the seed multiplication stage, in 2003/04. The seed produced will allow large-scale adoption in 2004/05. At this stage, it seems that only two Delta and Pine Land varieties, DP 424 BGII/RR and DP 468BGII/RR, will be planted on about 5,000-6,000 hectares each in 2003/04. Both varieties have been upgraded from Bollgard/Roundup Ready to Bollgard II/Roundup Ready. Both will have the Bollgard gene too. The Stoneville variety ST 5222B2, made available for planting in 2003/04, will not be in stacked gene form. However, Stoneville plans to introduce Bollgard II stacked gene varieties in the Roundup Ready gene in 2004/05. In the meantime, field testing of other varieties will continue and Stoneville may bring forward more varieties on a commercial scale in 2004/05.

Australia has capped the area devoted to Bollgard cotton (called Ingard in Australia) to 30% of the total area since the adoption of transgenic varieties in 1996/97. Australia planned to plant 5,000 hectares of Bollgard II in 2002/03 mainly for seed increase. During 2003/04, Bollgard II will be planted on about 50,000 hectares while the area under Bollgard will go down accordingly. Australia plans to replace all Bollgard cotton area with Bollgard II varieties in 2004/05.

Bollgard and Bollgard II technologies will both continue to be available for many years. Countries may have other considerations but cost is one of the limitations for the easy spread of genetic engineering technology. It is hoped that, as more insect resistant genes are identified and adopted, other countries may have easier access to the older genes.

## Technology Fee for Bollgard II

Bollgard II varieties have the ability to control a broader spectrum of lepidopterans, thus the potential to save more on insecticides. The increase in savings will depend on the population of the target pests controlled. Bollgard II provides better control of fall armyworm *Spodoptera frugiperda*, beet armyworm *Spodoptera exigua*, cabbage looper *Trichoplusia ni*, soybean looper *Pseudoplusia includens* and if these pests are not a serious threat, Bollgard II may not bring any savings in insecticide use as the additional Bt gene will be more costly to farmers.

Monsanto has fixed the technology fee for Bollgard II at US\$99/ha, which again will depend on the variable seed drop rate in the USA, as was the case for Bt cotton. Growers who decide to

go for Bollgard II cotton will pay the same technology fee irrespective of seed size/rate used to plant a particular area. The technology fee for Bollgard cotton in the USA is US\$79/ha and less in states that have lower insecticide savings. It is assumed that the technology fee for Bollgard II will also be different among states in the USA.

In the past, Monsanto has charged Australian cotton growers more for the same technology offered to U.S. cotton growers because in Australia farmers have higher savings in insecticides. It is assumed that the same philosophy will continue with Bollgard II.

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# Limitations on Organic Cotton Production

Organic cotton has been produced for centuries, but it was first officially certified in 1989/90 by Turkey, followed by the USA. Other common names used for organic cotton, particularly at the beginning of production, are green cotton, biological cotton and environment-friendly cotton. There are countries where no insecticides or synthetic fertilizers are used to grow cotton, but production is not sold as organic because it lacks certification. In order to claim that cotton is organic and receive a premium price, cotton production must be recognized as organic by a certifying organization.

Certifying companies, which are well-known among producers, buyers and processors of organic cotton, have established their own organic cotton production standards. The number of certifying companies is small, and standards may vary among them. The Technical Information Section of the International Cotton Advisory Committee has kept track of organic cotton

production in the world for many years and has published many articles on the subject. However, in some cases, data from some countries has been unavailable, and the Section has been unable to update the information. It is assumed that production has not increased beyond the experimental stage in countries other than India, Turkey and the USA.

## Organic Cotton Production in the USA

The Organic Trade Association, a membership-based business association representing the organic industry in North America through its Organic Fiber Council, has been able to keep a record of organic cotton production in the USA. In the USA, organic production prohibits the use of genetically engineered varieties, irradiation or sewage sludge, as well as toxic and persistent pesticides and synthetic fertilizers.

### Organic Cotton in the USA

| Year    | Area<br>(ha.) | Production<br>(tons) |
|---------|---------------|----------------------|
| 1990/91 | 364           | 330                  |
| 1991/92 | 1,331         | 820                  |
| 1992/93 | 2,552         | 2,155                |
| 1993/94 | 5,019         | 4,274                |
| 1994/95 | 6,417         | 5,365                |
| 1995/96 | 9,966         | 7,425                |
| 1996/97 | 4,362         | 3,396                |
| 1997/98 | 3,662         | 2,852                |
| 1998/99 | 3,791         | 1,878                |
| 1999/00 | 6,793         | 2,955                |
| 2000/01 | 4,370         | 1,860                |
| 2001/02 | 4,592         | 2,155                |
| 2002/03 | 3,660         |                      |

In the USA, most organic cotton is produced in Texas, where cotton yields are the lowest in the country. Four other states, Arizona, California, Missouri and New Mexico, together planted 24% of the organic cotton area in the USA in 2002/03. The same trend is expected in 2003/04. Unfortunately, sufficient information to produce organic cotton successfully is not available. In Texas, where organic cotton production has sustained so far, the Texas Department of

Agriculture and the Texas Organic Cotton Marketing Cooperative are active and provide advice in addition to certification. More information on the Organic Trade Association can be found on their web page at <http://www.ota.com>.

## Organic Cotton Yields in the USA

Growers have adopted organic cotton on their own for many reasons, including the elimination of hazardous pesticide usage, reduced costs of production and environmental safety. However, the available literature does not indicate that farmers have adopted organic cotton production in order to improve yields. It can be assumed that the elimination of the two major inputs-synthetic fertilizers and insecticides-should bring a drastic reduction in yields. The current cropping systems in almost all cotton growing countries consistently require synthetic fertilizers. Unlike insecticides and herbicides, synthetic fertilizers are needed every year and in the same quantities if no major changes have occurred in the cropping system. In contrast, pes-

ticide use will depend on pest pressure. If there are more weeds in one particular year, more herbicides will be used, and insect pressure will determine the number of sprays required to control insects. The use of other chemicals like growth regulators, desiccants and defoliant that are also prohibited in organic farming is almost constant over the years, but the elimination of synthetic fertilizers may eliminate the need to spray chemicals to control undesirable vegetative growth.

The most appropriate yield comparison is the performance of the same variety on the same farm under organic and conventional practices. Though there would be differences among farmers, countries and years, a trend could be developed on how much yield increase/reduction can be expected under organic conditions. It would be even more desirable to calculate the cost of production per kg of lint or seedcotton. Unfortunately, no such data are available from any country.

In the absence of desirable data as mentioned above, a comparison of USA organic cotton versus the average yield for the country for the same years is presented here. The national average yield is for all cotton and for all states in the USA, while organic yields are based on the total organic cotton area and total production in the USA.

The data show that organic cotton yields can be higher or lower than conventional cotton yields in a given year. In the last twelve years, from 1990/91 to 2001/02, the average shows that organic cotton yields were 6% lower compared to the conventional average yield for the country. However, the average of the last six years, from 1996/97 to 2001/02, shows a 24% reduction in yield under organic conditions compared to conventional production. The data for the last three years, from 1999/00 to 2001/02, show that on average organic cotton yields were 39% lower than the national average yield during the same time. These data indicate that, in the first six years of organic cotton production, on average organic cotton growers harvested 13% higher yields than the national average. However, recent data for the last six years and three years indicate that the difference between organic cotton and conventional production is widening. The last six-year period coincides with the adoption of transgenic cotton in the USA, which has a positive effect on yield, and organic cotton yields have been significantly lower, from 1998/99 to 2001/02.

## Organic Cotton in Turkey

Turkey is a pioneer in producing organic cotton. Organic cotton production started in Turkey in Kahramanmaraş in the Eastern Mediterranean region in 1989/90. The project was called Good Food Foundation and was followed by a second multinational project initiated in Salihli (Manisa) in the Aegean region by Rapunzel, a German company. Turkey significantly increased its organic cotton production during 1999/00 and 2000/01. According to Aksoy (2003), Turkey alone produced close to 10,000 tons of organic cotton in 1999/00 and 2000/01. In Turkey, there are small growers owning 15-20 hectares who produce organic cotton, and on average organic cotton growers

### Organic and Conventional Cotton Yields in the USA

| Year    | National Yield | Organic Yield |         |
|---------|----------------|---------------|---------|
|         | (kg/ha)        | (kg/ha)       | Percent |
| 1990/91 | 711            | 906           | 127     |
| 1991/92 | 731            | 616           | 84      |
| 1992/93 | 783            | 845           | 110     |
| 1993/94 | 679            | 852           | 126     |
| 1994/95 | 794            | 836           | 105     |
| 1995/96 | 602            | 745           | 124     |
| 1996/97 | 792            | 779           | 98      |
| 1997/98 | 762            | 779           | 102     |
| 1998/99 | 702            | 495           | 71      |
| 1999/00 | 680            | 435           | 64      |
| 2000/01 | 708            | 426           | 60      |
| 2001/02 | 790            | 469           | 59      |

| Organic Cotton Production in the World (tons) |         |         |         |         |         |         |         |         |         |         |         |         |         |
|-----------------------------------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Country                                       | 1990/91 | 1991/92 | 1992/93 | 1993/94 | 1994/95 | 1995/96 | 1996/97 | 1997/98 | 1998/99 | 1999/00 | 2000/01 | 2001/02 | 2002/03 |
| Argentina                                     | -       | -       | -       | -       | 75      | 75      | -       | -       | -       | -       | -       | -       | -       |
| Australia                                     | -       | -       | 500     | 500     | 750     | 400     | 300     | 300     | -       | -       | -       | -       | -       |
| Brazil                                        | -       | -       | -       | 1       | 5       | 1       | 1       | 1       | 5       | 10      | 20      | -       | -       |
| Benin                                         | -       | -       | -       | -       | -       | -       | 1       | 5       | 20      | 20      | 30      | -       | 92      |
| Egypt                                         | -       | -       | 50      | 150     | 600     | 650     | 625     | 500     | 350     | 200     | 200     | -       | -       |
| Greece                                        | -       | -       | -       | -       | 300     | 150     | 125     | 100     | 75      | 50      | 50      | -       | -       |
| India                                         | -       | -       | 200     | 250     | 400     | 925     | 850     | 1,000   | 825     | 1,150   | 1,000   | -       | -       |
| Israel                                        | -       | -       | -       | -       | -       | 50      | 50      | 20      | -       | 140     | 180     | 540     | 392     |
| Kenya                                         | -       | -       | -       | -       | -       | -       | -       | 5       | 5       | 5       | -       | -       | -       |
| Mozambique                                    | -       | -       | -       | -       | -       | 100     | 75      | 50      | -       | -       | -       | -       | -       |
| Nicaragua                                     | -       | -       | -       | -       | 20      | 20      | 20      | 20      | -       | -       | -       | -       | -       |
| Paraguay                                      | -       | -       | -       | 100     | 75      | 50      | 50      | 50      | -       | -       | -       | -       | -       |
| Peru                                          | -       | -       | 200     | 675     | 900     | 900     | 600     | 650     | 650     | 500     | 550     | -       | -       |
| Senegal                                       | -       | -       | -       | -       | -       | 1       | 10      | 10      | 50      | 125     | 200     | -       | -       |
| Tanzania                                      | -       | -       | -       | -       | -       | 10      | 100     | 100     | 100     | 200     | 250     | -       | 500     |
| Turkey                                        | 17      | 34      | 101     | 400     | 609     | 548     | 548     | 1,000   | 726     | 9,878   | 9,698   | -       | -       |
| Uganda                                        | -       | -       | -       | -       | 25      | 75      | 300     | 450     | 250     | 200     | 275     | -       | 200     |
| USA                                           | 330     | 820     | 2,155   | 4,274   | 5,365   | 7,425   | 3,396   | 2,852   | 1,878   | 2,955   | 1,860   | 2,155   | -       |
| Zimbabwe                                      | -       | -       | -       | -       | -       | -       | -       | 1       | 5       | 5       | -       | 2-3     | 2-3     |

suffered a 5.4-7.4% reduction in yield. The paper suggests that some varieties suffered as high as 17-22% losses in yield. Varietal differences were significant.

Fiber quality was similar in both conventional and organic farming systems. Data for the year 2001/02 suggest that farmers received premium prices for organic cotton-26% when farmers sold seedcotton and 20% if they sold lint. The data comes from TARIS, a large farmers' cooperative that plans to expand organic cotton. TARIS started producing organic figs in 1992, followed by organic raisins in 1997, and organic olives in 1999. The organic cotton project was initiated in 1999, and by then the cooperative already had enough experience in producing crops under organic conditions. The success of organic cotton in Turkey comes from experience, as contract farmers are the ones producing most of the organic cotton and very little production is directly initiated by the farmers themselves. Turkey has a full chain of organic cotton products and most organic cotton is processed to produce summer clothing, T-shirts, baby wear, towels and home textiles.

## Limitations to Organic Production

There are many reasons why organic cotton production has not extended to other countries. Nineteen countries tried to produce organic cotton during the 1990s. But many of them have already stopped, not for lack of desire or demand for such cotton, but for economic reasons. Insecticides need to be eliminated from the cotton production system because they are dangerous to apply, have long-term consequences on the pest complex, and deleterious effects on the environment. Also, heavy reliance on pesticide use has pushed many countries out of cotton production.

The Organic Trade Association undertook an extensive effort in 2002/03 to identify the problems with organic cotton production in the USA. The Organic Fiber Council of the Organic Trade Association contacted all organic cotton growers in the USA and tried to collect information through a survey. The ICAC Secretariat also undertook a survey of U.S. organic cotton growers in 1994, but satisfactory information for sound conclusions could not be obtained because many growers were reluctant to share information. ICAC's survey focused on two issues: 1) cost of production of organic cotton versus conventional cotton, and 2) price premium on organic cotton. According to the survey undertaken by the Organic Fiber Council in 2002, the main problems for organic cotton producers are weed management in the absence of herbicide use, defoliation (due to the prohibition of herbicides) and insect control. Some farmers also complained about seed treatment, which is not permitted in organic certification. In the USA, even organic cotton is picked by machines, thus defoliation is a serious problem that hand-picked cotton does not have.

The following factors have limited the expansion of organic cotton production. Suitable measures must be adopted to promote appropriate production practices if organic cotton production is to expand. Certain comments may be specific to cotton, but most others will apply to organic production in general.

## Suitable Varieties

Cotton producers in all nineteen countries mentioned adapted current varieties to organic production practices. Commercially grown varieties have been tested and developed for high input conditions. Under such conditions, any genotype not perform-

ing well will automatically be discarded. Varieties performing well under optimum conditions may not be able to maintain their yield level without synthetic fertilizers and insecticides. Breeding material for organic cotton production has to be screened under organic conditions.  $F_2$  single plants, progeny rows or bulks should be continuously grown under organic conditions to select for organic production. In the last three decades, emphasis has been placed on varieties shorter in stature, earlier in maturity and responsive to high doses of fertilizers. Shifting effective fruiting positions closer to the main stem and on lower branches has been pursued. High responses to fertilizers and a shift in fruiting positions are desirable characters for high input use, but may not be desirable in the absence of synthetic fertilizers. Similarly, the response of early and closer to the main stem fruiting needs to be investigated in comparison with genotypes with scattered fruiting positions on the plant.

Varieties that are suitable for high fertilizer use have been grown under organic conditions. Consequently, such varieties must have suffered heavier losses in yield than expected, discouraging farmers from continuing organic production. There is a need to develop varieties suitable for organic production conditions, maybe not as high yielding as normal varieties but hardy and able to produce good yields under organic conditions. Varieties for organic production must be developed under organic conditions.

### Fertilizer Use

Synthetic fertilizers are applied to cotton and to other crops in order to meet nutrient needs for the plant. Nutrient needs change from minimum to maximum for N, P and K during the course of development. Nitrogen, which leaches with water and can be lost through evaporation, must be applied when needed for optimum plant growth and fruit bearing. This is the reason why the timing of applications and dosage are critical for realizing optimum yields. P and K can stay in the soil and be used when needed, but yields are seriously affected if the timing or dosage for nitrogen are changed.

Short stature plants are expected to behave differently in the absence of synthetic inorganic fertilizers. Early maturing varieties, which are usually shorter in stature, enter into the fruiting phase earlier than tall growing cultivars and are also meant to form bolls at a higher rate. Such genotypes need fertilizers from the soil and any setback at this stage is directly related to loss in yield. Green manuring and organic fertilization can be employed to maintain the required nutrient supply, but the availability of nitrogen to the level of inorganic fertilization cannot be achieved. There is a need to find better alternatives for synthetic fertilizers so that the plant does not suffer due to insufficient nutrient supply, particularly nitrogen.

### Pest Control

The cotton plant is naturally vulnerable to a variety of insects, which are going to attack under organic growing conditions. Insect pressure can be lowered by enhancing biological con-

trols to compensate for the lack of insecticide use. The cotton plant has one of the best built-in compensation systems of many field crops. It can make up for early losses, but it cannot make up for a loss suffered after a certain time because cotton growing conditions have a certain cut-out period when the plant ceases to bear more flowers and bolls. This happens because the plant becomes physiologically exhausted and is unable to carry out physiological processes at the required rate, or because ambient conditions have changed and do not allow for normal growth. All out efforts have to be made to save the maximum number of buds, flowers and bolls from the very beginning, as provided by insecticides. Hence, it is necessary to find alternate means of insect control. Multi-adversity resistance can play a greater role in organic cotton production than in conventional cotton growing.

### Production Technology

Conventional cotton requires a technology package that includes the best use of inputs and production practices. Systems of disseminating the package might differ, but in most countries, it is free and delivered directly by the extension service to farmers' doorsteps. The advice, or technology package, on how a producer can achieve maximum yield includes guidance, from variety selection, planting time, soil preparation, elimination of weeds, irrigation, insect control, all the way to picking and storage of seedcotton until it is sold. Australian cotton producers achieve the highest or second highest yields in the world, almost three times the world average, and they still hire private consultants for advice on production technology. In the USA, the system is different and farmers rely on more than one source of information. In most West African countries, advice comes along with input supplies. In many Asian countries, advice on production technology is the responsibility of governments and is delivered through a broad network of extension workers especially trained in technology dissemination.

Whatever the system may be, organic cotton farmers need advice, without which they can be risking their investment. Unfortunately, whatever little advice on organic cotton is available is not authenticated or equivalent to conventional production technology packages. It is wrong to assume that the elimination of fertilizers, pesticides and other agrochemicals would simplify cotton production practices. On the contrary, it is more challenging to grow cotton without agrochemicals, but organic cotton growers lack advice on recommended production practices.

### Lack of Information on Cost of Production

When fertilizers and insecticides were first adopted in most countries, cotton yields started to increase. The development of suitable varieties further enhanced the effect of high input use. However, current trends indicate that average yields are not increasing and that the cost of conventional cotton production continues to inflate, affecting the economics of producing cotton. Higher costs without yield increases are forcing farm-

ers to abandon cotton production, or to continue producing but under increased costs to governments that subsidize production one way or the other. Cotton growers in many countries have become more interested in reducing the cost of production if they cannot increase yields, as an indirect way of increasing profitability.

Organic production practices generally lower costs of production per unit area. But the economics of reducing expenditures incurred in growing a unit area are determined by the effect on yield. Lower total costs/ha do not mean lower costs per kg of lint, if the elimination of prohibited agrochemicals significantly reduces yield/ha. It is generally accepted that the elimination of synthetic agrochemicals will affect yields, but the impact on yields and the cost of production have not been established. Potential organic cotton growers will definitely consider the economics of growing organic cotton versus conventional production before making a decision. Unfortunately, information on cost of production of organic cotton versus conventional production under various sets of production conditions is not available. In the absence of such information, farmers are reluctant to adopt organic production.

### Price Premium

It is anticipated that certified organic cotton will fetch a premium price. However, it has been seen that organic producers have not received premiums, and sometimes they have been penalized for producing lower grade cotton because of bollworm damage. Data have been collected for over ten years in many countries, but there is no conclusion regarding the average premium or discount on organic cotton versus conventional cotton. Without a price premium, organic cotton will not be profitable because of reductions in yield. Solid indications that price premiums can be expected would encourage organic production.

### Need for Alternate Inputs

Synthetic fertilizers and insecticides were adopted because of the high benefit-cost ratios. The impact of fertilizer and insecticide use is quick and very effective. Nitrogen can be applied and becomes available to the plant immediately, or it can be applied for slow release. Herbicides and insecticides provide immediate effects. The elimination of synthetic fertilizers and pesticides deprives the plant two major safeguards, i.e. protection against nutrient starvation and protection against insect pests, unless alternative systems with equally quick and effective action are available. Unfortunately such alternatives are not available. Manual and mechanical means of weed control exist but they are not feasible for large scale farming systems, and alternatives to insecticides and fertilizers are slow in action. Although claims have been made about no yield reduction, and even in some cases claims of higher yields, there is every likelihood that organic production will give lower yields compared to conventional practices. A mixed message is not helping new producers to adopt organic production.

### Tied Crop Rotations

Rotating crops in the same field is one of the means of improving soil fertility. A general principle of rotation in planting says that deep-rooted crops should be followed by shallow-rooted crops. But once a cotton field becomes eligible for full certification, usually after a transitional period of three years, it must be planted only with organic crops when cotton is not in the field. Thus, cotton must rotate with another organic crop, or the field should be left fallow for recuperation of soil fertility, which may not be acceptable under the current pressure for high cropping intensity. If an organic cotton producer is willing to plant a rotation crop, he has to learn how to produce the second crop under organic conditions also.

### Non-Organic Genetically Engineered Cotton

Genetically engineered Bt cotton cannot be certified as organic even if grown under organic conditions, although the Bt gene and the new series of genes being introduced to provide cotton with resistance to a variety of pests could contribute significantly to enhance organic production. Without going into a discussion of whether or not transgenic varieties should be eligible for certification as organic, transgenic cotton has not encouraged organic production, but rather negatively affected any plans to expand organic production of cotton.

### Certification

Certification and labeling are areas that need attention. Certification is an additional cost and in some cases organic producers have complained about it. The de-facto organic cotton produced in many countries, particularly in Africa, could be easily certified as organic if the service were available free, the same way extension services are available to farmers at no cost in many countries.

### Marketing

The most sensitive aspect of organic cotton production and expansion lies in marketing, and market linkages between cotton producers and international buyers, ranging from access to market information and distribution channels. This article has discussed only the most important production limitations, but processing and marketing issues have not been discussed here.

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## Short Notes

### • Performance of Bt Cotton in India in 2002/03

Three Bt cotton hybrids were grown on a commercial scale for the first time in India during 2002/03. Mahyco Monsanto Biotech (India) Ltd., which is a joint venture between Monsanto and a local seed company mainly involved in hybrid cottonseed production, distributed 105,000 seed packets for planting in 2002/03. Each packet contained 450 grams of Bt seed and 120 grams of non-Bt seed. The price of each packet was US\$32 (1,600 Indian rupees). The three hybrids, Bt Mech 12, Bt Mech 162 and Bt Mech 184, were planted in six states on a total area of 42,052 hectares. Reports in November 2002 indicated that the Bt hybrids were affected by a new wilt disease that was referred to as "parawilt." Later, it was revealed that the parawilt phenomenon was a physiological disorder that occurred when Bt cotton hybrids were exposed to prolonged dry-spells or unusually high temperatures during boll formation, followed by heavy rains. Reports showed that conventional and non-Bt hybrids were also affected by parawilt, but Bt hybrids had greater boll loads so, their environmental stress was more severe. No other disorder or strange effect was noted on the Bt hybrids.

The American bollworm *Helicoverpa armigera* and the pink bollworm *Pectinophora gossypiella* are the two major bollworms that affect cotton in India. Most sprays to protect flower buds and bolls are directed to control these two worms. Monsanto undertook a survey of selected farmers with experience in Bt cotton production in various states. Data from Tamil Nadu was not available at the time of publication of this report; however, Monsanto data indicate that on average cotton growers saved on insecticides and also got higher yields with Bt hybrids over non-Bt hybrids.

The Central Institute for Cotton Research (CICR), Nagpur also conducted an independent assessment of Bt hybrids. The CICR assessment was on a smaller scale and limited to only ten farmer fields in two villages under the Institute Village Linkage Program, near Nagpur in Maharashtra.

Under non-irrigated conditions, the average yield of MECH 184Bt was 971kg/ha compared to its refuge of 819 kg/ha and check hybrid of 737 kg/ha. The Bt hybrid was not sprayed against bollworms, while the check plot was sprayed 2-3 times during the fruiting period. The yield for MECH 162Bt was 867 kg/ha, and for the refuge was 753 kg/ha. The check hybrid's yield was 686 kg/ha. In this trial, the refuge crop was sprayed 1-2 times while the check plots received 2-3 sprays. The data from the institute present seedcotton yields, and they plan to work out the economics of planting Bt hybrids.

The overall performance of Bt cotton hybrids in India was encouraging on 80% of the area devoted to the genetically engineered varieties. However, bollworm pressure was lower than usual in 2002/03, and it is believed that Bt hybrids prove more successful under high bollworm pressure. In 2002/03, farmers did save on insecticides, but the cost of seed was higher-US\$82/ha compared to US\$26/ha for the best non-Bt hybrid seed. In a country like India, where cotton is a poor farmers' crop, the initial investment of US\$82/ha is a constraint to the adoption of Bt hybrids.

However, the data reported above belong to Monsanto, which has a vested interest in the promotion of the technology. The benefits of the Bt gene cannot be applied universally and in cotton areas throughout India. Many factors will determine the economic benefits of the technology, including pest pressure and farmers' agronomic practices and pest management skills. The Bt technology may have no

**Performance of Bt Cotton in India – 2002/03**

| State          | Bt Cotton Area<br>(ha.) | Insecticide Savings<br>(US\$/ha.) | Increase in Income<br>(US\$/ha.) |
|----------------|-------------------------|-----------------------------------|----------------------------------|
| Andra Pradesh  | 3,400                   | 56                                | 305                              |
| Gujarat        | 6,532                   | 27                                | 379                              |
| Karnataka      | 6,714                   | 31                                | 334                              |
| Madhya Pradesh | 3,638                   | 49                                | 494                              |
| Maharashtra    | 16,685                  | 37                                | 373                              |
| Tamil Nadu     | 5,083                   | Not available                     | Not available                    |
| India          | 42,052                  | 40                                | 377                              |

Exchange rate: Indian rupees 48 = US\$1

economic advantage if target pests do not exist in a particular area or do not pose economic losses.

The initial approval for commercial use in India is valid for three crop years, from April 2002 to March 2005. Cotton is the first transgenic crop approved for commercial cultivation in India. Mahyco Monsanto Biotech (India) Ltd. plans to produce one million packets of Bt seed for distribution during 2003/04 to plant over 400,000 hectares, enough to have an impact on the national yield.

### • Economic Impact of Bt Cotton

Many reports and papers published around the world since 1996 show the multifold advantages of planting transgenic Bt cotton varieties. The most common benefits are higher yields, lower cost of production, environmental safety in the form of lower insecticide use, and the safety of field workers, particularly the ones handling insecticide in small scale farming systems. The nature of the benefits depends on growing conditions and the pest complex.

Researchers have studied trial results comparing Bt and non-Bt cotton. Apparently, there is a difference between the benefits indicated in independent trials and the benefits in trials conducted by Monsanto, with the Monsanto data being conservative. Average results over five years from independent (non-Monsanto) trials suggest that Bollgard growers received a total benefit of US\$123/ha, with an average yield increase of 10% over non-Bollgard growers. Similar five-year-average data from Monsanto indicate a benefit of US\$99/ha and a 6% average increase in yield for Bollgard growers. The conclusions are consistent, but the yield differential is crucial. The assertion that in Bollgard cot-

ton the cost of controlling bollworms and budworms will be lower may not be true under all production conditions. The addition of the technology fee, combined with high pest pressure, could raise the total cost of insecticides and spraying in Bollgard cotton. More recent data from the USA for 2002/03 indicate that Bollgard cotton requires 1.5 fewer sprays to control insects on average. The savings in the number of sprays ranged from only 3% to as high as 62%. This means that savings in insecticide applications are not the most important factor for economic evaluation of the Bt gene technology. The real benefit to farmers comes in the form of an increase in yields as a result of better pest control.

Researchers at the Department of Agricultural and Resource Economics, University of Arizona, USA, studied the impact of Bt cotton on international prices. In his paper presented at the 2003 Beltwide Cotton Conferences, Dr. George Frisvold concluded that the world average price has been lower by 2.65 cents/kg of lint due to the planting of Bt cotton in the world. According to Dr. Frisvold, international prices would have been lower by 1.54 cents/kg of lint if Bt cotton had been planted only in the USA. Planting of Bt cotton in the rest of the world lowered the world average price by 1.11 cents/kg of lint.

**Total Number of Sprays on Bollgard and Non-Bollgard Cotton in the USA – 2002**

| State          | Non-Bollgard | Bollgard | % Reduction of Sprays |
|----------------|--------------|----------|-----------------------|
| Alabama        | 1.76         | 1.16     | 34                    |
| Arkansas       | 9.45         | 6.06     | 36                    |
| Georgia        | 4.10         | 1.30     | 62                    |
| Mississippi    | 5.72         | 4.29     | 25                    |
| North Carolina | 2.66         | 0.88     | 67                    |
| South Carolina | 1.80         | 1.75     | 3                     |
| Tennessee      | 4.91         | 3.20     | 35                    |
| Texas (East)   | 4.64         | 2.95     | 36                    |
| Texas (West)   | 4.75         | 4.25     | 10                    |
| Virginia       | 3.00         | 2.00     | 33                    |
| Average        | 4.28         | 2.78     | 34                    |

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