

FACTS
SERIES

BT
COTTON
IN INDIA



... A SUCCESS STORY FOR THE ENVIRONMENT
AND LOCAL WELFARE



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January 2013

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Summary

Nowhere on earth will you see more cotton fields than in India. Cotton cultivation has experienced a remarkable growth story over the last decade: the production, the yield per hectare and the total area on which cotton can be cultivated have all increased to record high levels. The Indian cotton farmers now account for 21 % of the global production.

Of course there is more than one reason for this increase in cotton cultivation in India. Nonetheless, anyone who examines the figures will note that this growth is associated with the introduction of Bt cotton, a type of cotton plant that has had the genes of the soil bacterium *Bacillus thuringiensis* inserted – hence the name Bt cotton. These genes produce proteins that protect the plant against the bollworm, a notorious pest of cotton plants.

Bt cotton was officially admitted in India for commercial cultivation from the 2002 – 2003 growth season. Currently, 87 % of all Indian cotton plants is Bt cotton. In 2011, seven million of the eight million Indian cotton farmers adopted for Bt cotton.

Research demonstrates that the Indian farmer who cultivates Bt cotton sprays less insecticide and achieves a higher yield. At the end of the day, he makes more profit, the environment benefits from the lower use of insecticides and – because Bt cotton farmers spray fewer insecticides – the farmers are at a lower risk of poisoning. In addition, it is not only the large farmers who benefit from the advantages of Bt cotton: for the millions of small farmers – and their families – the revival in small-scale cotton farming is an important instrument in trading extreme poverty for a more dignified existence. In other words, Bt cotton in India is the story of a high-technology agricultural innovation that can also offer benefits to smaller farmers.

Research has also demonstrated that there is no link between the high number of suicides amongst Indian farmers and whether or not they cultivate Bt cotton. Such a link is repeatedly suggested by non-governmental organizations, lobby groups and the media. There are other factors that play a much more important role. The lack of affordable credit and the absence of any social security to cope with failed harvests are the most prominent factors.

Nevertheless, we should not consider Bt cotton a miracle solution. There is definitely local variation in the yield per ha and cotton farmers are not always informed about the benefits and disadvantages of the cottonseeds that they purchase. In addition, cotton cultivation in general remains a burden on the environment due to the large quantities of water used. The cultivation of Bt cotton is no exception to this rule.

To summarize, Bt cotton should be viewed as an useful tool with which the Indian farmer can protect his crop in an environmentally friendly and sustainable manner against its most important enemy, the bollworm.

FACTS AND FIGURES

- More than 10 million hectares of Bt cotton were cultivated in India in 2012. With a total of 11.6 million hectares of cotton, this equates to an adoption of 93 %, an increase of 5 % compared to 2011.
- More than seven million of the eight million farmers opted for Bt cotton in 2012. These usually small farmers cultivate cotton on an average agricultural area of 1.5 ha.
- Prior to the introduction of Bt cotton in India, approximately 5.9 g of pesticides was required for the production of 1 kg of cotton. In 2010, less than 0.9 g of pesticides was used for the production of 1 kg of Bt cotton, which equates to an almost seven-fold reduction in the use of pesticides.
- As Bt cotton farmers spray less frequently, the numbers of cases of pesticide poisoning have decreased by 88 %.
- An IFPRI overview study demonstrates that Indian Bt cotton farmers spend 31 % to 52 % less on insecticides and achieve a 34 % to 42 % higher cotton yield per ha than farmers who cultivate traditional cotton. Although the total production cost price of Bt cotton is 15 % higher than that of non-Bt cotton, the income of Bt cotton farmers is 53 % to 71 % higher.
- The Bt technology is at least 19 % responsible for the increase in yield per ha of the Indian cotton cultivation in the past 10 years.
- The British advisory service PG Economics estimates that Bt cotton produces a profit of between US\$ 82/ha and US\$ 356/ha compared to traditional cotton. The profit varies depending on the region, the expertise of the farmer and the weather conditions.
- From 2002 – 2003 until the growing season of 2009 – 2010, the Bt technology has ensured an increased profit of US\$ 9.4 billion for the Indian farmers, as calculated by the PG Economics advisory service.
- Partly due to Bt cotton, India has developed into the second biggest producer of cotton since 2006, after China, but ahead of the United States. Today, India accounts for 21 % of the global cotton production. India changed from a net importer of cotton fibers to an exporter: in 2009 – 2010, more than 8 million bales of 170 kg were exported, accounting for US\$ 2.3 billion in revenue.
- Cotton is the second most important field crop in Indian for the production of table oil: 13.7 % of the 7.88 million tons of table oil produced in India is obtained from cottonseed. Cottonseed has also become the main ingredient (33 %) in processed animal fodder, with soy, rapeseed and groundnuts lagging far behind.

The advance of cotton cultivation

Until the turn of the century, the cultivation of cotton led a changeable existence in India. Good harvests were mixed in with failures. However, the Indian cotton cultivation has been on the up over the last decade: increasing numbers of farmers are sowing cotton, whilst the production and the yield have increased significantly. At least some of this growth

is due to the introduction of biotech cotton. This cotton carries genes from the bacterium *Bacillus thuringiensis*, hence the name Bt cotton. These genes produce proteins that protect the plant against bollworms, an infamous pest in cotton. Bt cotton was officially first introduced in India during the 2002 – 2003 growing season.



FIGURE 1A

THE HECTAREGE COTTON INCREASED SIGNIFICANTLY FOLLOWING THE INTRODUCTION OF BT COTTON IN 2002.

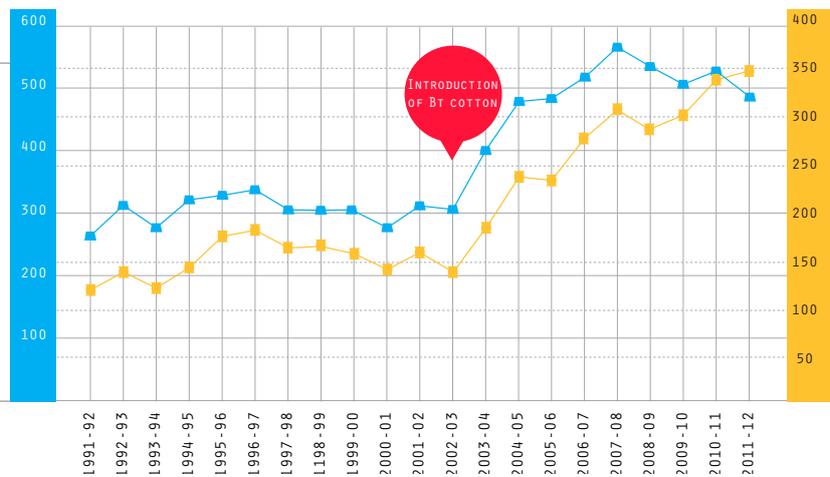
SURFACE AREA IN 1 MILLION HA



FIGURE 1B

INTRODUCTION OF BT COTTON IN 2002 RESULTED IN INCREASING YIELD.

YIELD IN KG / HA



PRODUCTION IN 100 000 BALES



No country on earth cultivates more cotton than India¹. According to official figures from the Ministries of Agriculture and Textile, 10.3 million hectares (ha) of cotton were sowed in India during the 2009 – 2010 growing season.² This is a significant increase compared to one decade earlier: between 1991 and 2002, the total Indian hectareage for cotton cultivation varied between 7.4 and 9.3 million ha (figure 1A). During the 2002 – 2003 and 2003 – 2004 growing seasons there was even a dip, with 7.7 and 7.6 million ha respectively. This was followed by a systematic increase to more than 10 million ha in 2009 – 2010.

This growth shows no sign of ending either. In October 2012, the same

ministries estimated that the total area for cotton cultivation increased to 11.2 million ha during the 2010 – 2011 growing season, an increase of 7 % compared to the previous year. The expected figures for 2011 – 2012 will be truly historic: 12.2 million ha will be sown, which is 18 % more than in the two previous growing seasons.

Even more telling is the increase in the production (yellow line in figure 1B). Between 1991 and 2003 production varied between 11.9 and 17.9 million bales of 170 kg. Since then, production has increased steadily to more than 30 million bales (in 2007 – 2008 and 2009 – 2010). This figure is expected to reach 35.3 million bales for 2011 – 2012. The increase is partly due

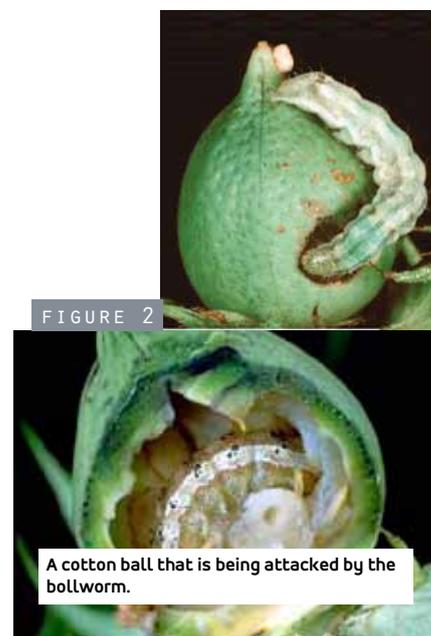
to the expansion of the cultivation area, but to a greater extent it is due to an improvement in the yield per ha (blue line in figure 1B): this rose from approximately 300 kg/ha in the period 1991 – 2003 to over 500 kg/ha since 2006 – 2007.

In a recent report³, the Indian Office of the Textile Commissioner suggests two reasons to explain this increase in productivity: the widespread use of Bt cotton (see editorial) and the use of “good agricultural practices” including fertilizer and optimum water use. “The synergy between both factors has resulted in a remarkable increase in yield”, according to the report, “the expectation is that the current high productivity will at least be maintained.”

BT – A PRODUCT FROM NATURE

Insects can cause severe damage to agricultural crops. In traditional agriculture they are targeted with an arsenal of insecticides. Some of these are harmful to humans and the environment. However, there are also more environmentally friendly alternatives, such as the toxins produced by the soil bacterium *Bacillus thuringiensis* (usually abbreviated to “Bt”). These Bt proteins are only toxic to some moth and butterfly caterpillars and/or larvae of beetles and mosquitoes. They are harmless to other animals, including humans.

Biotechnology was used to insert the genes that code for the Bt proteins into the DNA of agricultural crops such as corn and cotton. This resulted in the names Bt corn and Bt cotton. These toxins make Bt corn more resistant to being eaten by – for example – the larvae of the corn borer and Bt cotton more resistant against the bollworm. The use of Bt as a spraying agent is permitted in organic farming, but when Bt is sprayed it also kills sensitive insects that do not feed on the plant. Enabling crops to produce Bt themselves means that only the insects that feed on the crop are killed.



1 James C 2011. Global Status of Commercialized Biotech/GM Crops. Brief 43. Executive summary.

Available via <http://www.isaaa.org/resources/publications/43/executivesummary/default.asp>

2 Office of the Textile Commissioner, Ministry of Textiles, Government of India, Statewise area under cotton and production as per Cotton Advisory Board (CAB).

Update of 18 April 2012. Available via <http://www.txcindia.com/>

3 Office of the Textile Commissioner, Ministry of Textiles, Government of India, Information submitted to the Commission for Agricultural Costs and Prices, December 2011.

Available via <http://www.txcindia.com/html/CACP%202012-2013.pdf>

Coincidental discovery of a biological insecticide

In 1901 the Japanese biologist Shigetane Ishiwatari was searching for the reason of mass death in silkworms. He linked this death to a bacterium that he named *Bacillus sotto*.^{4,5} However, the research results of Ishiwatari remained largely unnoticed in the West, until Ernst Berliner isolated the same bacterium from dead meal moth larvae in 1911. Berliner named the bacterium *Bacillus thuringiensis* (Bt), after the German state of Thüringen. The mill where the meal moths were found was located in this state. The bacterium has officially been known under this name since then. Unlucky for Ishiwatari.

In 1915, Berliner also reported that Bt bacteria produce large protein crystals from the moment they start forming spores⁶. However, it was not until 1956 that Canadian scientists demonstrated that the capacity of the bacteria to kill insects was due to these crystals. This discovery resulted in a rapid increase in research involving Bt bacteria.

Today, thousands of different strains of this bacterium have been identified. They occur all over the world in all soil types: from beaches and deserts to tundra and clay substrates. The thing that they all have in common is that when they form spores, they also form the typical protein crystals which are visible under the microscope.

Bio-insecticides with a high specificity

The crystals produced by the *Bacillus thuringiensis* bacteria can account for up to 30 % of the total protein mass of the bacterium. They consist mainly of so-called cry proteins (from “Crystal”), which are packaged in the crystal as “pro-toxins”. This means that an activation step is required before they become harmful to the insect. This activation usually takes place in the intestine of the caterpillar or the larva.

Together, the various Bt strains produce more than 300 different proteins with insect-killing activity. Each protein has its own specificity: some Cry proteins are only toxic to butterfly and moth caterpillars (Lepidoptera), others are mainly targeted against larvae of beetles (Coleoptera) or mosquitoes (Diptera). It is due to this specificity that the Cry pro-toxins used in agriculture today are not toxic to mammals or humans. An overview^{7,8} of the various Cry pro-toxins is provided in Table 1.



TABLE 1. OVERVIEW OF CRY PROTEINS AND THEIR INSECT-KILLING ACTIVITY

Protein	Size (in kDalton)	Specificity
Cry 1: sub groups A(a->F), B(a->d), C(a,b), D(a,b), E(a,b), F(a,b), G(a,b), H(a,b), I(a,b), J(a,b), K(a)	130-138	Caterpillars (Lepidoptera)
Cry 2: sub groups A(a->c)	69-71	Caterpillars (Lepidoptera) and mosquito larvae (Diptera)
Cry 3: sub groups A(a), B(a,b), C(a)	73-74	Beetle larvae (Coleoptera)
Cry 2: sub groups A(a), B(a)	73-134	Mosquito larvae (Diptera)
Cry 5 to Cry 22	35-129	Various

The protein crystals of some Bt strains contain only one type of Cry protein, others contain a mixture. For example, the crystal of the Bt strain “kurstaki HD-73” only contains the Cry1Ac toxin, whilst the “HD1” strain contains 5 different Cry toxins (Cry1Aa, Cry1Ab, Cry1Ac, Cry2Aa and Cry2Ab) in its protein crystals.

4 Ibrahim MA et al 2010. *Bacillus thuringiensis*: a genomics and proteomics perspective. *Bioeng Bugs* 1, 31-50.

5 University of California San Diego. *Bacillus thuringiensis* educational website. http://www.bt.ucsd.edu/bt_history.html

6 Some types of bacteria, including *Bacillus*, produce round or oval “survival bodies” in which a copy of their genetic material is stored.

These bodies – called spores – are particularly resistant to heat, cold and drought. As soon as the conditions become more favourable, the spores transition into bacteria again.

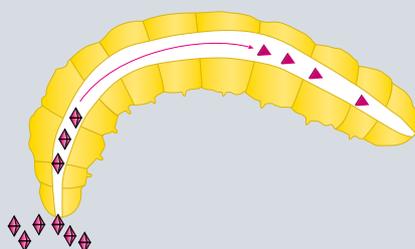
7 Crickmore N et al 1998. Revision of the nomenclature for the *Bacillus thuringiensis* pesticidal crystal proteins. *Microbiol Mol Biol Rev* 62, 807-813.

8 Schnepf E et al 1998. *Bacillus thuringiensis* and its pesticidal crystal proteins. *Microbiol Mol Biol Rev* 62, 775-806.

Mechanism of action

The Cry proteins inhibit the appetite of Bt sensitive caterpillars and larvae, resulting in death through starvation. The way in which this happens is similar for all types of Cry proteins. The site of action is the insect's intestines.

1. The caterpillars and larvae ingest the Cry pro-toxins by eating plants that have been sprayed with Bt crystals or by eating plants that produce the Cry pro-toxins (via biotechnology).
2. A digestive enzyme in the mid-section of the insect's intestine cleaves the pro-toxin. This converts the pro-toxin into an active Cry toxin.



Bt crystals are converted to Crytoxins in the intestines of the caterpillar

3. The Cry toxins bind to a cadherin receptor protein on the membrane of the insect's intestinal cells.

The exact molecular and cellular mechanisms that eventually result in the death of the insect can vary per insect family. Therefore, there are different models to explain the general mechanism of action of Bt⁹ figure 5.

The model by Bravo¹⁰ states that – following recognition of the Cry toxins by the cadherin receptor – several Cry toxins are joined together. The resulting complex then drills a hole in the membrane of the intestinal epithelial cells. They are assisted in this process by (GPI anchored) receptors present in the membrane. The creation of this pore results in vital ions leaking from the cell. The cells die and can no longer absorb nutrients.

The model by Zhang¹¹ suggests that the binding of the Cry toxin to the cadherin receptor inside the cell sets off a series of biochemical reactions that ultimately result in cellular suicide (apoptosis).

Finally, the Jurat-Fuentes model¹² combines both models. In this model, the intestinal cells die as a result of a combination between pore formation and cellular signaling processes. The latter is thought to be regulated by specific phosphatases.

4. Despite the differences in models, the end result is the same: large numbers of epithelial cells die at various sites in the insect's intestine. The caterpillars and larvae can no longer absorb nutrients and are exposed to infections by bacteria and other microorganisms. Only those insects that have the required receptors to recognize the Cry toxins are sensitive. Such Cry specific receptors are not found in humans or other mammals.^{13,14} Various *in vivo* and *in vitro* studies demonstrate that Bt proteins are not harmful to humans and animals.^{15,16}

9 Pigott CR, Ellar DJ 2007. Role of receptors in *Bacillus thuringiensis* crystal toxin activity. *Microbiol Mol Biol Reviews* 71, 255-281.

10 Bravo et al 2004. Oligomerization triggers binding of a *Bacillus thuringiensis* CryIAb pore-forming toxin to aminopeptidase N receptor leading to insertion into membrane microdomains. *Biochim Biophys Acta* 1667, 38-46.

11 Zhang X et al 2006. A mechanism of cell death involving an adenylyl cyclase/PKA signaling pathway is induced by the CryIAb toxin of *Bacillus thuringiensis*. *Proc Natl Acad Sci USA* 103, 9897-9902.

12 Jurat-Fuentes JL, Adang MJ 2006. Cry toxin mode of action in susceptible and resistant *Heliothis virescens* larvae. *J Invertebr Pathol* 92, 166 – 171.13

13 Shimada N et al 2006. Binding of CryIAb toxin, a *Bacillus thuringiensis* insecticidal toxin, to proteins of the bovine intestinal epithelial cell: an *in vitro* study. *Appl Entomol Zool* 41, 295-301.

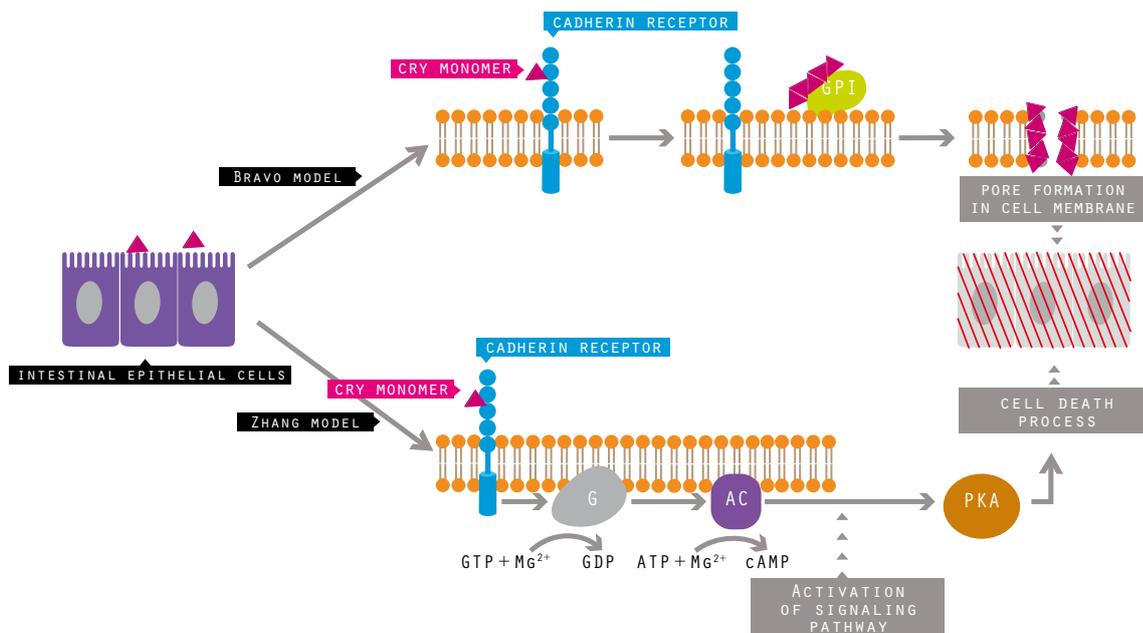
14 Kuiper HA et al 2001. Assessment of the food safety issues related to genetically modified foods. *Plant J* 27, 503-528.

15 Bondzio A et al 2008. Impact of *Bacillus thuringiensis* toxin CryIAb on rumen epithelial cells (REC) – A new *in vitro* model for safety assessment of recombinant food compounds. *Food Chem Toxicol* 46, 1976-1984.

16 Shimada N et al 2006. Effect of feeding calves genetically modified corn Bt11: a clinico-biochemical study. *J Vet Med Sci* 68, 1113-1115.

FIGURE 5

MODE OF ACTION OF BT INSECTICIDE. AFTER BINDING TO THE CADHERIN RECEPTOR, VARIOUS MOLECULAR PROCESSES RESULT IN CELL DEATH OF THE INTESTINAL EPITHELIAL CELLS. GPI = GLYCOSYL PHOSPHATIDYL INOSITOL; G = G PROTEIN; AC = ADENYLYL CYCLASE; PKA = PROTEIN KINASE A



BT – WHAT AND HOW

From pre-war pesticide spray to modern biotechnology

Farmers have been using the Bt bacteria to protect their crops against insects since 1920. In most cases, mixtures of Bt spores and Bt crystals were used to spray the surface of plants. The first commercial Bt product – under the name Sporine – was marketed in France in 1938⁵. The USA followed in 1958 and the American “Environmental Protection Agency” (EPA) registered various Bt products as insecticides from 1961⁵.

However, use remained limited. Largely due to the success of synthetic insecticides. However, as soon as the harmful effects of these insecticides on humans and the environment became clear – and due to increasing numbers of insects that are resistant to synthetic insecticides – the interest in Bt increased. Initially the interest was limited to organic farming, but later the more traditional farmers also took note. In the late 1980s biotechnologists succeeded in inserting genes for various Bt toxins in plants, so that the plants started synthesizing the toxins themselves. This meant that all parts of the plant were protected against insects for the entire life cycle of the plant: from germinating seed to harvestable plant.¹⁷

In the USA, the first Bt crop – potatoes – for commercial farming was accepted in 1995.¹⁸ Various other crops would follow. The most successful Bt crops are Bt corn – with an increased resistance to the caterpillar of the stem borer and/or root borer – and Bt cotton, which offers protection against the bollworm. Initially, these were biotech crops containing only one Cry toxin gene, but the use of Bt crops in which several Cry genes are active simultaneously are increasingly being used to prevent the development of resistance in insects (see also further along in this dossier)¹⁹.

FIGURE 6

IMAGE OF INSECTICIDE BASED ON BT ACTION



<http://www.arbico-organics.com/product/175>

17 Van Gysel A 2003. Genen op je bord (Genes on your plate). Flemish Scientific Library Nature and Technology. Part 76.

18 United States Environmental Protection Agency (US EPA). EPA's Regulation of Bacillus thuringiensis (Bt) Crops. Available via <http://www.epa.gov/opbppd1/biopesticides/pips/regofbt crops.htm>

19 James C 2012. ISAAA Brief 44 Global Status of Commercialised Biotech/GM Crops: 2012, Distribution of Biotech Crops, by Crop, p.211-215, International Service for the Acquisition of Agri-Biotech Applications (ISAAA).

2 Rapid adoption of Bt cotton

Bt cotton was admitted in India from the 2002 – 2003 growing season. Today, nearly 90 % of all cotton plants cultivated in India are Bt cotton plants. Seven of the eight million Indian cotton farmers have adopted for Bt cotton.

From 0 % to 90 %

Bt cotton – that carries an insecticide-producing gene from the soil bacterium *Bacillus thuringiensis* in its genetic material – was officially admitted in India for commercial planting in 2002. During the 2002 – 2003 growing season there were 54,000 Indian cotton farmers who sowed Bt cotton on approximately 50,000 ha. In the following years the use of Bt cotton sky-rocketed (see figure 7): the area doubled in 2003 – 2004, quadrupled in 2004 – 2005 and the 1 million ha threshold was passed in 2005 – 2006. The number increased to 3.8 million ha in 2006 – 2007, to 7.6 million in 2008 – 2009 and to 8.4 million ha in 2009 – 2010. At that point, more than 80 % of all Indian cotton plants were Bt cotton plants.²⁰

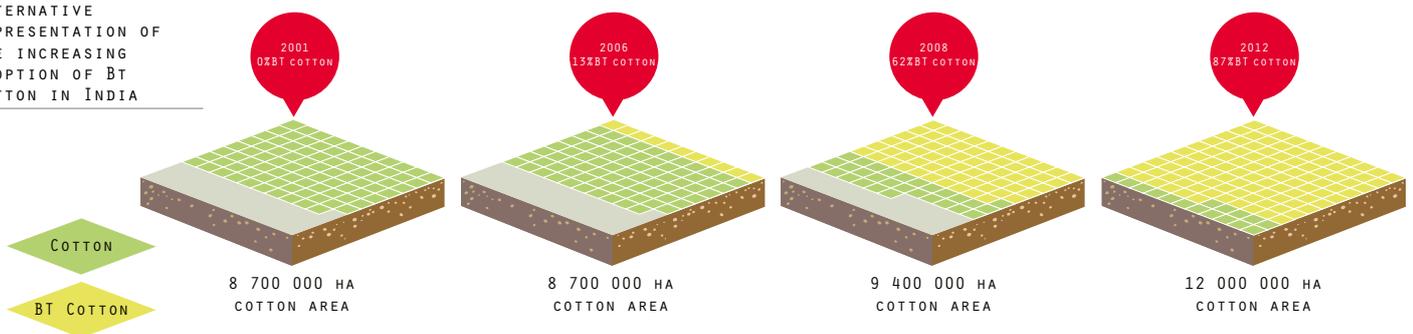
FIGURE 7A

THE BENEFITS OF BT COTTON CULTIVATION RESULT IN MASS ADOPTION OF BT BY INDIAN FARMERS.



FIGURE 7B

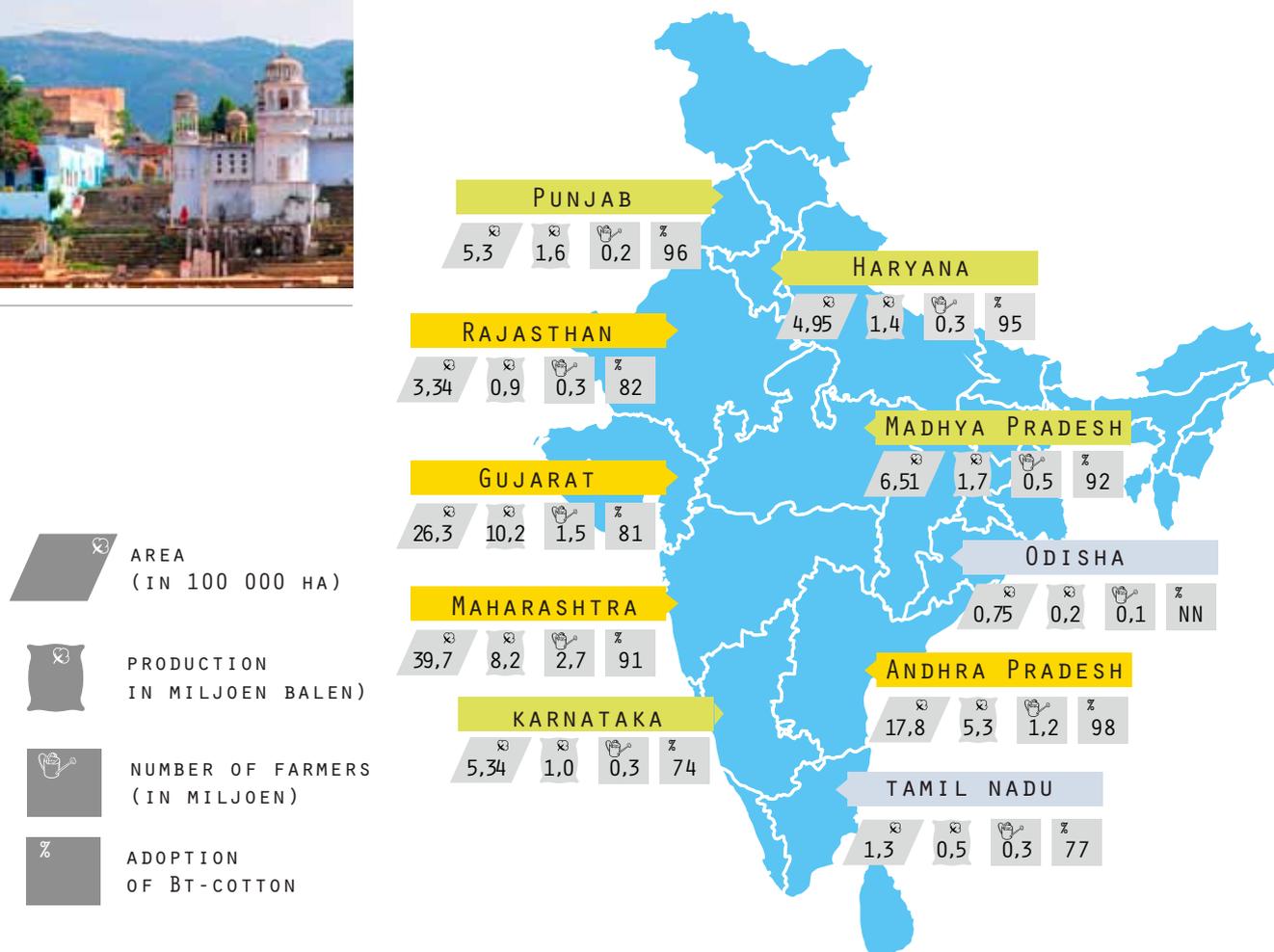
ALTERNATIVE REPRESENTATION OF THE INCREASING ADOPTION OF BT COTTON IN INDIA



20 James C 2012. ISAAA Brief 44 Global Status of Commercialised Biotech/GM Crops: 2011, India, p.61-82, International Service for the Acquisition of Agri-Biotech Applications (ISAAA).

FIGURE 8

MOST IMPORTANT COTTON-PRODUCING PROVINCES IN INDIA.



In 2011 – 2012 the Indian area used for Bt cotton cultivation exceeded the 10 million ha mark. This means that – according to government calculations – 87 % of the Indian cotton fields were Bt cotton fields.²¹ In a number of Indian cotton provinces the adoption of Bt cotton even exceeds 90 % (see figure 8). Examples include Punjab (96 %), Haryana (95 %), Maharashtra (91 %), Madhya Pradesh (92 %) and Andhra Pradesh (98 %). Furthermore, provinces where Bt cotton has not been grown much have caught up significantly over the last year (Rajasthan from 64 % to 82 %, Gujarat from 59 % to 81 %, Karnataka from 49 % to 74 % and Tamil Nadu from 33 % to 77 %).²

7 million farmers

The number of farmers cultivating Bt cotton displays the same increasing curve: from 50,000 in 2002, to 100,000 in 2003, 300,000 in 2004, 1 million in 2004 to 6.3 million in 2010. In 2012, 7.2 million of the 8 million Indian cotton farmers have chosen to sow Bt cotton.²⁰

Furthermore, it is not only the large cotton farmers who prefer to grow Bt cotton. On the contrary, the average Indian cotton farmer cultivates 1.5 ha of cotton and even the smaller farmers have switched to Bt cotton in large numbers.²⁰

At least 19 % contribution to increased yield

However, the key question remains what the actual contribution of Bt cotton is to the increase in Indian cotton production and the improved yield. In a recent report from the International Food Policy Research Institute (IFPRI)²² by Guillaume Gruère and Yan Sun calculate that Bt cotton is responsible for at least 19 % of the general increase in yield of Indian cotton farming.²³ This contribution is concentrated in particular around the period after 2005.

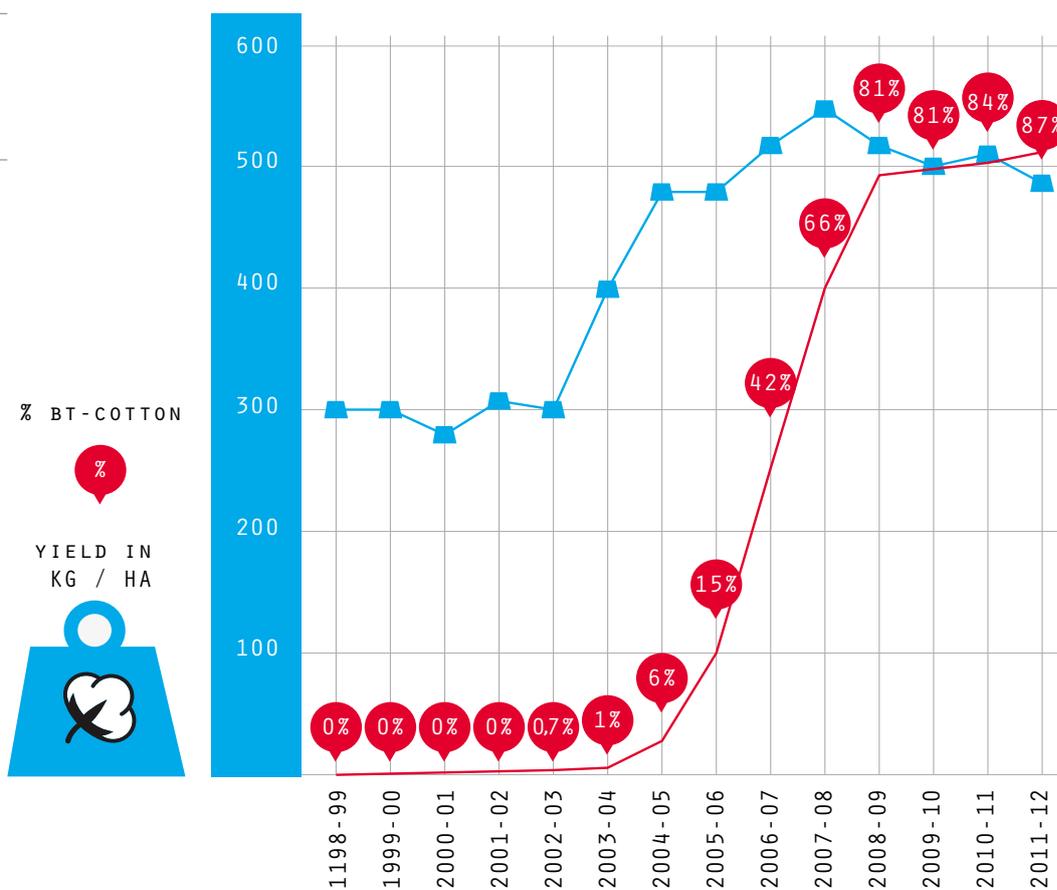
The conclusions that Gruère and Sun were able to draw about the contribution of Bt cotton to the increase in yield per ha during the early adoption period (2002 – 2005) are less clear-cut. According to official figures, very little Bt cotton was cultivated during this period, but the average yield did increase. “However, according to the IFPRI researchers: “Various reports^{24,25} suggest that Bt cotton seeds were already available

in India long before 2002”. “This was particularly the case in Gujarat, a province that was a forerunner in India in achieving increased yields”. Unfortunately there are no official figures – either for Gujarat or other provinces – although BT cotton was cultivated there in the initial period. To summarize, if non-official Bt cotton also contributed to the increase in yield between 2002 and 2005, then the figure of 19 % is a low estimate and the actual contribution could be significantly higher.

Other key factors that have contributed to the increased yield are the use of fertilizers, hybrid seeds that are better suited to local growth conditions, improved agricultural practices, optimum use of pesticides and expansion of irrigation systems.

FIGURE 9

INTRODUCTION OF BT COTTON CONTRIBUTED TO INCREASED YIELD IN COTTON PRODUCTION



22 The International Food Policy Research Institute (IFPRI) is part of the consortium of research centres acknowledged by the Consultative Group on International Agricultural Research (CGIAR). IFPRI receives research funds from governments, private foundations and international and regional organisations.

23 Gruère GP, Sun Y 2012. IFPRI Discussion Paper 01170 Measuring the Contribution of Bt Cotton Adoption to India's Cotton Yields Leap. Available via <http://www.ifpri.org/sites/default/files/publications/ifpridp01170/pdf>.

24 Gupta AK, Chandak V 2005. Agricultural biotechnology in India: ethics, business and politics. Int. J. Biotechnology 7, 212-227.

25 Herring RJ 2007. Stealth Seeds: Bioproperty, Biosafety, Biopolitics. J Dev Stud 43, 130-157.

The small farmer also benefits

Has the individual Indian cotton farmer also benefited from Bt cotton? The scientific research that has been performed indicates that this is the case. Thanks to Bt technology, Indian farmers spend less money on insecticides and achieve higher yields. At the end of the day, they gain more from Bt cotton.

However, Bt cotton is by no means an undivided success story in all cotton areas in India for all Indian farmers. Seedlings that were not adapted to the local growing conditions, lack of information and education and dubious sales practices have fuelled the social controversy surrounding Bt cotton.

Comparative studies – a search for unambiguous results

Comparative research between farmers who cultivated crop variety A compared to farmers who cultivated crop variety B is usually the acid test used to demonstrate whether one variety performs better than the other. Comparative studies can also provide an indication of a possible benefit or disadvantage of Bt cotton. Nevertheless, these studies have not always resulted in consensus in the past. On the contrary.

The industry usually paints a positive picture of Bt technology. A series of non-governmental organizations then contradict these conclusions, with or without supporting figures. They paint a scenario of a fiasco, with failed harvests, high costs, large debts, farmers who end up in poverty and who are even forced to sell their organs or see suicide as the only escape.^{26,27,28} A story of catastrophe that is lapped up by the media.

Government institutions and academic research centers are more nuanced in their conclusions and appear – in most cases – to underwrite the benefit of Bt technology, also for the

individual²⁹⁻³⁵, small and poor farmers. However, academics have also voiced criticism.³⁶

It is standard practice to perform meta-analyses if conflicting results are published. All published data are combined and analyzed once more. Such a systematic analysis of the available empirical findings was performed in 2008 by Guillaume P. Gruère, Purvi Mehta-Bhatt and Debdatta Sengupta of the International Food Policy Research Institute (IFPRI).³⁷



26 Shiva V et al 2000/2002. Seeds of Suicide. The Ecological and Human Cost of Globalisation of Agriculture. Research Foundation for Science, Technology and Ecology (RFSTE).
 27 Sahai S, Rahman S 2003. Performance of Bt Cotton in India: Data from the First Commercial Crop. Economic & Political Weekly 38, 3139-3141.
 28 Qayum A, Sakkhari K 2005. Bt Cotton in Andhra Pradesh. A Three-year Assessment. The First Ever Sustained Independent Scientific Study of Bt cotton in India. Deccan Development Society, Andhra Pradesh Coalition in Defense of Diversity, Permaculture Association of India.
 29 Qaim M, Zilberman D 2003. Yield effects of genetically modified crops in developing countries. Science. 299, 900-902.
 30 Bennett R et al 2006. Farm-level economic performance of genetically modified cotton in Maharashtra. Applied Economic Perspectives and Policy 28, 59-71.
 31 Narayanamoorthy A, Kalamkar SS 2006. Is Bt Cotton Cultivation Economically Viable for Indian Farmers? An Empirical Analysis. Economic & Political Weekly 41, 2716-2724.
 32 Sadashivappa P, Qaim M 2009. Bt Cotton in India: Development of Benefits and the Role of Government Seed Price Interventions. AgBioForum 12, 172-183. Available via <http://www.agbioforum.org/v12n2/v12n2a03-sadashivappa.htm>
 33 Qaim M 2010. Benefits of genetically modified crops for the poor: household income, nutrition and health. New Biotechnol 27, 552-557.
 34 Rao NC, Dev SM 2009. Biotechnology and Pro-Poor Agricultural Development. Economic & Political Weekly 44, 56-64.
 35 Kathage J, Qaim M 2012. Economic impacts and impact of dynamics of Bt (*Bacillus thuringiensis*) cotton in India. Proc Natl Acad Sci USA 109, 11652-11656.
 36 Glover D 2010. Is Bt Cotton a Pro-Poor Technology? A Review and Critique of the Empirical Record. J Agrar Change 10, 482-509.
 37 Gruère GP et al 2008. IFPRI Discussion Paper 00808 Bt Cotton and Farmer Suicides in India. Reviewing the Evidence. Available via <http://www.indiaenvironmentportal.org.in/files/btcotton.pdf>

In their report³⁷, the IFPRI scientists calculated that Bt cotton resulted in an average increase in income for individual farmers of between 53 % and 71 % compared to non-Bt cotton. Although the production costs of Bt cotton are 15 % higher than traditional cotton due to the higher seed price, this increase is compensated by the decreased expenditure on pesticides (31 % - 52 %) and a higher yield per ha (34 % - 42 %). Gruère's meta-analysis is based on 22 separate comparative studies that monitored the production and yield of 12,931 cotton fields. The scientists also distinguished between studies that were published in "peer-reviewed" journals (and possibly of higher quality) and other studies. However, they found the same trends in both groups of studies. When examined per province and per growing season, Bt cotton also resulted in a higher

income for farmers in all cases. The order of magnitude of these figures was confirmed in a recent study³⁵ by Jonas Kathage and Matin Qaim from the Georg-August University in Göttingen (Germany). They collected data from 1655 cotton fields of 533 Indian farmers in the period 2002 - 2004 and 2006 - 2008. This is the first study that draws comparisons over such a long period. Their research demonstrates that Bt cotton results in an increased yield per ha by 24 % and that Bt farmers make 50 % more profit on their cotton crop compared to non-Bt farmers. They concluded that "Bt cotton has resulted in significant and sustainable advantages, which have contributed to the positive economic and social development in India."

A difficult start

Gruère from the IFPRI concluded that the context in which Bt cotton was introduced in the first few years was sometimes problematic. The scientists confirmed significant variation between studies and locations during the first growing season of Bt cotton.³⁷ In a number of cases the Bt cotton varieties produced disappointing results. During those initial years there were only a few Bt cotton hybrids on the market and they were not adapted to the very diverse growing conditions in a vast country such as India.

In addition to unsuitable varieties, unfavorable weather conditions, the low cotton price and non-adapted farming practices (due to misinformation and a lack of education) also played a role. The circulation of "pirate Bt cotton" also contributed to the problem. It is not clear how many farmers purchased cotton seed sold by dishonest traders as Bt cotton that did not in fact contain Bt technology.³⁷

In their report "GM crops: global socio-economic and environmental impacts 1996-2010"³⁸, Graham Brookes and Peter Barfoot from PG Economics confirmed that the initial years of Bt cotton in India were certainly not a resounding success in all areas. However, since 2006 - when more than 60 Bt cotton hybrids were available and the additional cost of Bt cotton seed compared to classic hybrid seeds was limited to US\$ 20/ha or less by the government - all farmers started to see profits from Bt cotton. Based on comparative field studies and depending on the region and the expertise of the farmer, Brookes and Barfoot estimate that this profit lies between US\$ 82/ha and US\$ 356/ha. Since the introduction in 2002 - 2003 until the growing season 2009 - 2010, the introduction of Bt cotton has resulted in an increased profit for Indian farmers of US\$ 9.4 billion.



38 Brookes G, Barfoot P 2012. GM crops: global socio-economic and environmental impacts 1996-2010. PG Economics. Available via <http://www.news.agropages.com/UserFiles/Report/Pdf/201206081019083408.pdf>



Before and after Bt adoption

However, Ronald J. Herring from Cornell University in New York (USA) and N. Chandrasekhara Rao from the Centre for Economic and Social Studies in Hyderabad (India) argue that comparative studies between farmers and fields have their limitations, even when grouped in meta-analysis. They wrote in the journal *Economic & Political Weekly* of 5 May 2012 that “Field trials often suffer from skewed comparisons”.³⁹ “Which villages are compared to each other, which farmers, which crop varieties, which seasons. [...] Furthermore, the studies in a meta-analysis often vary in quality and do not use the same methodology.”

The question is whether there are more powerful instruments to highlight the benefits or disadvantages of Bt cotton. Herring and Rao state that this is the case. A suitable study approach could include the “before-and-after” method: how did the yield evolve in the same field, owned by the same farmer, under similar growing conditions at the time that he used traditional cotton varieties and after he switched to Bt technology?

The scientists collected data from 186 farmers in the province of Andhra Pradesh. Table 2 provides an overview of the costs and yields, expressed in Indian rupees per acre.⁴⁰ According to this study, the net income of these farmers increased by an average

of 209 % once they switched to Bt cotton. Although Bt seeds are more expensive and a greater investment in labor is required, the IFPRI scientists concluded that the net income of the farmers still increased significantly. Two parameters again favor Bt: a higher yield and lower expenditure on insecticides.^{34,41}

Furthermore, all farmers benefit from Bt cotton, including the small and mid-range farmers. Their yield increased by 39 % and 33 % respectively, resulting in their net income increasing by 186 % and 217 % respectively. The large farmers did benefit most from Bt cotton: the yield of their cotton harvest increased by 93 % and their income increased by 300 %. “But you can hardly blame Bt technology for this”, according to Martin Qaim from the Georg-August University in Göttingen (Germany)⁴². The reasonable distribution between the benefits and costs of a new technology “do not depend on the technology alone, but also on the institutional setting at national, regional and local level. For poor and small farmers it is often more difficult to obtain the correct information and education, to have access to adequate infrastructure, access to affordable credit, etc. In other words, they are less capable of fully utilizing the potential of the new technology.”⁴²

39 Herring JR, Rao NC 2012. On the “Failure of Bt Cotton”, Analysing a Decade of Experience. *Economic & Political Weekly* 18, 45-53.

40 1 euro is worth approximately 70 Indian rupees. 1 acre is approximately 0.4 ha.

41 Rao NC, Dev SM 2010. *Biotechnology in Indian Agriculture: Potential, Performance and Concerns*. New Dehli, India: Academic Foundation.

42 Qaim M et al 2009. Commercialized GM crops and yield. *Nat Biotechnol* 27, 803-804.

TABEL 2. COSTS AND YIELDS BEFORE AND AFTER THE ADOPTION OF BT COTTON (PER 'ACRE' IN RUPEES)

	Before adoption (non-Bt) (2004 – 2005 growing season)	After adoption (Bt) (2006 – 2007 growing season)	After adoption (Bt) (taking into consideration the inflation and market price differences)	Change (in %) (taking into consideration the inflation and market price differences)
Hired laborers	1 476	1 726	1 535	4
Labor with buffalo and oxen	855	906	806	-6*
Mechanical labor	587	886	788	34*
Seed	598	897	798	34*
Organic fertilizers	406	380	338	-17**
Fertilizers	1 603	1 723	1 532	-4
Insecticides	3 267	1 599	1 422	-56*
Irrigation	54	55	49	-9
Miscellaneous (repair and transport)	84	88	78	-7*
Total production cost	9 057	8 327	7 405	-18*
Yield (in quintals)	7,21	10,27	10,27	42*
Production cost per quintal	1 256	811	721	-42*
Gross income	12 338	19 722	17 540	42*
Net income	3 281	11 395	10 134	209*

Source: Herring RJ and Rao NC, *Economic & Political Weekly*, 2012;17 (8);45-54. The farmers who did not yet cultivate Bt cotton in 2004 – 2005 represented the “before adoption” group in this study scenario. These same farmers who had switched to Bt cotton in the season 2006 – 2007 formed the “after adoption” group. Changes are significant at the level 0.01* and 0.05** A quintal is a historical weighing unit usually defined as 100 units in pounds or in kg. In India 1 quintal is equal to 100 kg.

Women, hired laborers and the local economy

Qaim did point out that Bt cotton also generates indirect positive effects, in addition to a direct benefit in income for the farmer⁴². The higher cotton yields ensure more employment opportunity (e.g. during the cotton picking season and the processing of the cotton to textiles). They also stimulate the local transport sector and trade. Furthermore, the higher income for the farmers and agricultural laborers also ensures greater buying power and the subsequent boost to the local economy.

Based on his research^{42,43}, Matin Qaim estimates that every ha of Bt cotton creates a combined income (i.e. direct and indirect income combined) that is US\$ 246 higher than for farmers growing traditional cotton. For the entire cotton industry in India this translates to an additional profit exceeding US\$ 2 billion per year. US\$ 1.13 billion of this goes to the farmers and US\$ 830 million is in the form of additional indirect benefits to the local economy. Sixty percent of these benefits are passed on to poor and extremely poor families, with an average annual income below US\$ 500.

Remarkably, Bt cotton provides 55 % more work to women: more cotton seed fluff needs to be picked during the harvest and cotton picking is traditionally a woman’s job in India.⁴⁴ Many farmer’s wives also process some of the cotton to cotton thread. “In developing countries, the income of women benefits the entire family. An increase in that income almost always results in an improvement in the food situation, the health and the wellbeing of the children”, according to Qaim⁴⁴. A social impact study performed by Indicus Analytics – the most important Indian economic research centre – confirms these findings. Indicus Analytics polled 9300 households in 465 different villages that cultivated either Bt cotton or conventional cotton. This revealed that the children of Bt cotton farmers had better immunization rates and a significantly higher percentage attended school compared to children of farmers who grew conventional cotton⁴⁵.

43 Subramanian A, Qaim M. The impact of Bt Cotton on Poor Households in Rural India. *J. Develop. Stud.* 2010 Feb; 46 (2):295-311.

44 Subramanian A et al 2010. GM crops and gender issues. *Nat Biotechnol* 28, 404-406.

45 Indicus Analytics 2007. Socio-economic appraisal of Bt cotton cultivation in India. Indicus Analytics study.

Available via <http://www.indicus.net/media/index.php/blogspace/171-Two%20Studies%20show%20benefits%20of%20BT%20Cotton%20in%20India>

An useful tool, not a miracle solution

“The fact that Indian farmers have switched to Bt cotton in large numbers – and continue to sow Bt cotton – underwrites the success of the technology”, according to Herring and Rao.³⁹ Let us be fair: farmers are risk-averse, they do not readily adopt new technology, something that they are unfamiliar with. If they do switch and continue to support the new technology in large numbers it is because they benefit from it themselves. Their behavior is underpinned by logical and straightforward common sense and by a strong will to provide a dignified existence for themselves and their family with their small plot of land. Year upon year and generation after generation.

Nevertheless, we should not view Bt cotton as a miracle solution. Studies point to local variations in yield. However, the extent to which this variation can be linked to Bt technology is another question. If cotton harvests fail in certain regions, this may also be due to other factors: for example weather conditions, or poor agricultural practices, or the fact that some fields were not suitable to cotton growth. After all, the expansion of the area will result in using plots that are less suitable for cotton culture. These fields are equally unsuitable for conventional cotton and Bt cotton. For example, cotton cannot grow if there is no water, as cotton is a crop that requires a lot of water. And poor dry soils provide low yields. Bt technology will not be able to change this. Only varieties specifically developed for these growing conditions can help in this situation.

In other words, “the Bt technology is an useful tool with which the Indian farmer can protect his crop against its main enemy, the bollworm”, according to Herring and Rao.³⁹ “The story of catastrophe – though widely discussed in the press and therefore praised by all – lacks any scientific support and empirical basis. It clashes “immensely” with the adoption behavior of the Indian cotton farmers.”



No link between Bt cotton and suicides

The media suggests that Bt cotton is responsible for the suicide of thousands of Indian farmers. However, research reveals that there is no link between the suicides and the increasing degree of adoption of Bt cotton. On the contrary, in most areas where a lot of Bt cotton is cultivated the number of suicides appear to have decreased.

The NGOs, lobby groups and the media stressed the link between suicide and Bt cotton for years now.^{26,27,28} Almost the entire world believed the British Prince Charles when he stated bluntly in 2008: "I blame GM crops for farmers' suicides".⁴⁷ The supposed link between Bt cotton and the increase in the number of suicides amongst small farmers in India is based on the following assumption: farmers all across India incurred massive debts in

order to purchase expensive Bt cotton seed. When their crop failed or they did not achieve the expected additional harvest, they were unable to pay their debts and some of them only saw one escape: suicide. However, this was not the end of the argument. The image of Bt cotton seed was demonized further to become "suicide seed", "homicide seed" and even "genocide seed".⁴⁷

No direct indications

Following a thorough evaluation of the literature, IFPRI scientists Guillaume P. Gruère, Purvi Mehta-Bhatt and Debdatta Sengupta concluded that "all studies performed about the suicides of Indian farmers reveal a lack of quantitative data about the farmers involved. There has been no serious data collection or publication about either their background or the circumstances in which the suicides took place."³⁷ Some

examples of the essential questions to which there are no answers: What is the proportion of cotton farmers amongst the farmers who committed suicide? How many farmers who cultivated Bt cotton committed suicide? How many farmers committed suicide as a result of Bt cotton? To summarize: "the core of the argument that Bt cotton leads to suicide is based purely on hypotheses and not on any quantitative or empirical evidence", according to the IFPRI scientists.³⁷

More Bt, equal or fewer numbers of suicides

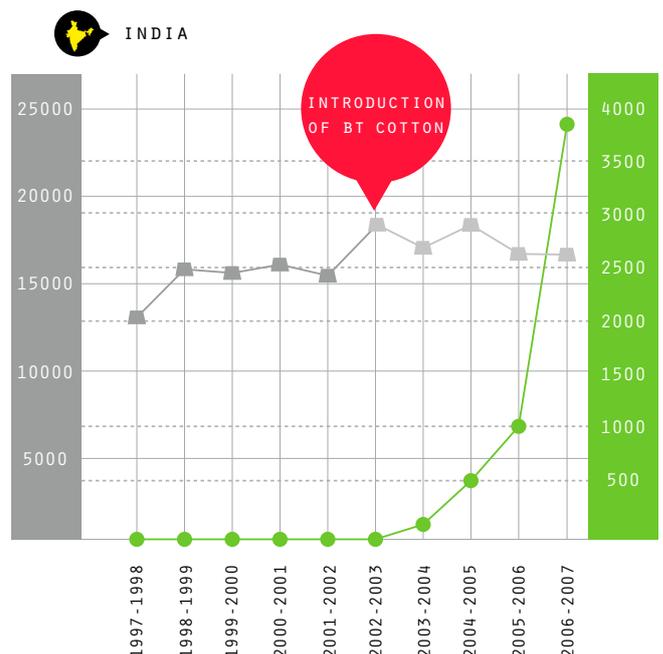
However, many organizations continue to hammer on about the fact that Bt cotton is to blame. However, anyone who looks at the figures will reach a different conclusion. Namely that the number of suicides across India are not related to the significant increase in the adoption grade of Bt cotton (see figure 10).

The same trend is observed at the level of individual cotton provinces, particularly Maharashtra and Gujarat (see figure 11). Since the introduction of Bt cotton in 2002, the number of farmers planting Bt cotton has risen exponentially, whilst the suicide figures have remained at the same level.

Furthermore, the IFPRI study shows that there is in fact a decrease in the number of suicides in the provinces of Madhya Pradesh and Karnataka. It seems extremely unlikely that Bt cotton is the main driving factor behind the suicide of Indian farmers.

FIGURE 10

NUMBER OF SUICIDES AMONGST FARMERS COMPARED TO THE ADOPTION OF Bt COTTON IN INDIA



46 Prince Charles. I blame GM crops for farmers' suicides. The Independent, 5 October 2008.

Available via <http://www.independent.co.uk/environment/green-living/charles-i-blame-gm-crops-for-farmers-suicides-951807.html>

47 Herring RJ 2009. Global Rifts over Biotechnology: What Does India's Experience with Bt Cotton Tell Us? Krishnamachari Memorial Lecture, Institute for Economic Growth, Delhi University. Available via <http://government.arts.cornell.edu/assets/faculty/docs/herring/KrishnamachariLectureFnRhv15.pdf>

FIGURE 11A

NUMBER OF SUICIDES IN MAHARASHTRA INCREASES OVER THE YEARS, BUT THE INCREASE IS NOT PROPORTIONAL TO THE INCREASE IN THE BT COTTON AREA



FIGURE 11B

THE NUMBER OF SUICIDES IN MAGHYA PRADESH DECREASES FOLLOWING THE INTRODUCTION OF BT COTTON

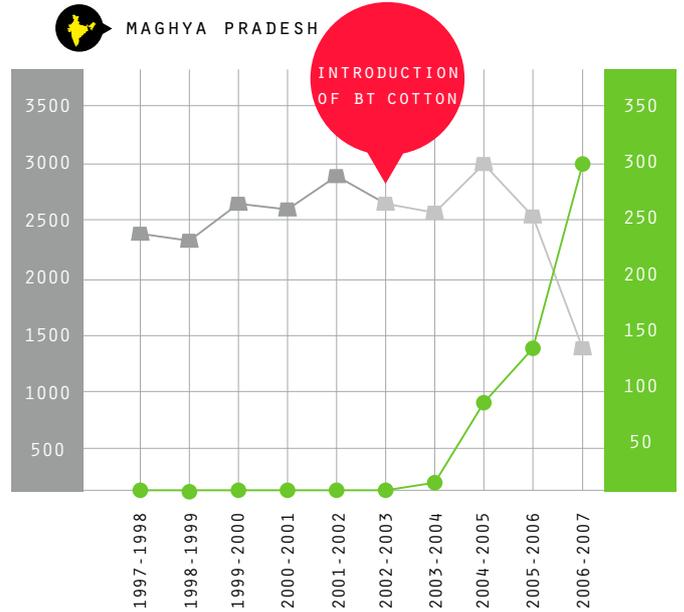


FIGURE 11C

THE NUMBER OF SUICIDES IN KARMATAKA DECREASED FOLLOWING THE INTRODUCTION OF BT COTTON

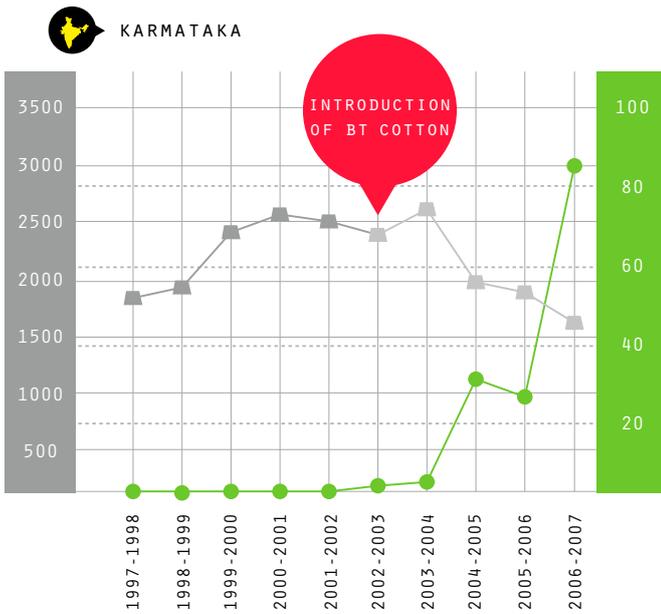
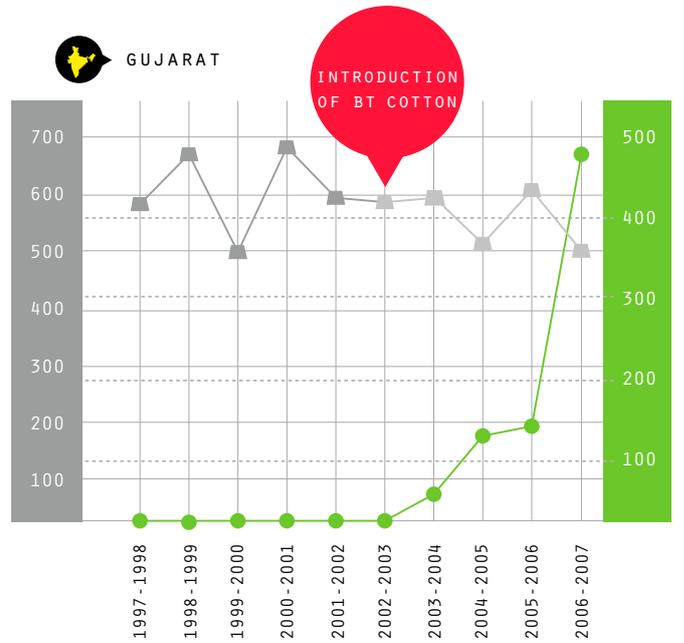


FIGURE 11D

THE NUMBER OF SUICIDES IN GUJARAT REMAINED STABLE THROUGH THE YEARS, WHILST BT COTTON WAS CULTIVATED INTENSIVELY



Lack of credit and social security

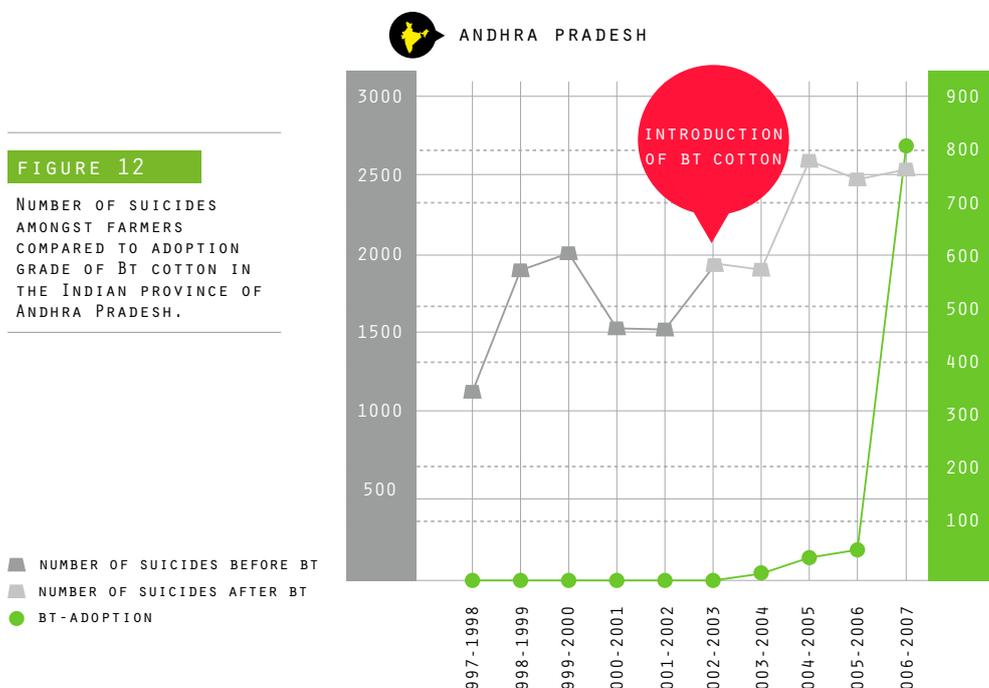
Whereas the number of suicides has stagnated – or even decreased slightly – over the last few years in most Indian cotton provinces, there was an increase in the province of Andhra Pradesh (see figure 12). The IFPRI report³⁷ concludes: “One cannot rule out that Bt cotton played a role in this region, albeit a marginal one. Other factors have contributed in equal measures and possibly to a greater extent.”

These factors include the weather conditions: the 2004 – 2005 growing season – in which the highest number of suicides were recorded in Andhra Pradesh – was relatively dry. There is also the low cotton price at market and the lack of affordable credit: most farmers have to borrow from non-official and uncontrolled credit lenders, sometimes resulting in exorbitant interest rates.

In addition, the expansion of the cotton area to regions less suitable to cotton may also have played a role. The cotton harvest is doomed to fail in these areas, regardless of whether the crop is Bt cotton or conventional cotton. And finally, India has no social security system in the event of disappointing harvests resulting in financial hardship for farmers.

The IFPRI report is clear and concise: “without doubt, Bt cotton is neither an essential nor an adequate condition for the suicides of Indian farmers. Bt cotton does not deserve the blame. There are other factors that play a much more important role: the lack of affordable credit and the absence of social security being the most prominent.”³⁷

Is this report the end of the discussion? “Probably not”, according to science journalist Cormac Sheridan.⁴⁸ “This is a debate in which emotions run high, [...] and the shocking lack of any hard primary data about the complex tragedy of suicide amongst Indian farmers will persist.” The Indian government faces an important task in providing clarity in this matter.



48 Sheridan C 2009. Doubts surround link between Bt cotton failure and farmer suicide. Nat Biotechnol 27, 9-10.

Year	Government decision	Background Bt cotton variety
2002	The “Genetic Engineering Approval Committee” (GEAC) and the Indian Ministry for Environment and Forestry admit 3 Bt cotton hybrids for commercial farming. The 3 hybrids are all of the “Bollgard I” (MON-531) variety. They were developed and tested by Maharashtra Hybrid Seeds Company Ltd. (Mahyco) in collaboration with Monsanto.	Bollgard I, based on ‘MON-531’ technology Scientists at Monsanto inserted the CryIAC gene obtained from <i>Bacillus thuringiensis</i> var. <i>Kurstaki</i> into cotton plants. The fact that the plant cells produce the CryIAC toxin makes them more resistant to the cotton bollworm (<i>Helicoverpa armigera</i>) and the pink bollworm (<i>Pectinophora gossypiella</i>). ^{49,50}
2004	GEAC admits a fourth Bollgard I hybrid.	
2005	16 additional Bollgard I hybrids approved.	
2006	GEAC approves three new Bt crops for use in Indian cotton farming: “Event-1” from the Indian company JK Seeds and “GFM” employing Chinese gene technology by Nath Seeds. The third approved Bt crop, “Bollgard II” (MON-15985) by Mahyco/Monsanto, is the first to include double protection. A further 42 new hybrids are also admitted.	Event-1 JK Agri Genetics from Andhra Pradesh inserted an altered cryIAC gene from the Bt var. <i>Kurstaki</i> HD73. The plant is protected against cotton bollworm (<i>Helicoverpa armigera</i>), the pink bollworm (<i>Pectinophora gossypiella</i>) and the “spotted” bollworm (<i>Earias vittella</i>). ⁵¹ GFM These plants contain a fused cryIAb/1Ac gene . They produce a toxin that consists of part CryIAb protein and part CryIAC protein. ⁵² Bollgard II, based on “MON-15985” technology Bollgard II crops carry the cry2Ab2 gene in addition to the CryIAC gene, so that the plant cells produce two toxins against the bollworm. ⁵³
2007	73 additional hybrids are approved, applying one of the 4 permitted Bt technologies.	
2008	GEAC permits the commercial cultivation of BNLA-601 cotton. Technology applied to the indigenous cotton variety Bikaneri Nerma.	BNLA-601 This Bt cotton crop carries a CryIAC gene and was developed based on the indigenous cotton variety Bikaneri Nerma. The research was performed by scientists at the University of Agricultural Sciences in Karnataka and the Central Institute of Cotton Research (CICR). The CICR is an institute in the public sector that belongs to the Indian Council of Agricultural Research (ICAR). ²⁰
2009	MLS-9124, developed by Metahelix Life Sciences in Karnataka, was deemed safe by the GEAC.	MLS-9124 This Bt cotton plant contains a cryIca1 gene and the toxin offers protection against nocturnal butterflies of the Spodoptera species. ⁵⁴
2011	Between 2002 and 2011, the GEAC approved a total of 884 Bt varieties for commercial cotton cultivation. The distribution is as follows: Bollgard I (215 hybrids), Bollgard II (528), Event-1 (41), GFM (96), BNLA-601 (2), MLS-9124 (2).	
2012 – 2015	The GEAC has granted permission for safety and field trials for 4 additional Bt crops. These are Bollgard II Roundup Ready Flex (MON-15985xMon-88913) by Mahyco/Monsanto, Widestrike by Dow AgroSciences, Event-1xEvent-24 by JK Seeds and GHB614 (Glytol cotton) by Bayer Biosciences.	Bollgard II Roundup Ready flex (MON-15985xMON-88913) The product of a cross between the herbicide-resistant cotton variety MON-88913 and the Bt cotton variety MON-15985. The plants carry the genes cryIAC and cry2Ab to offer resistance to bollworms and the CP4EPSPS gene , making them tolerant to the herbicide glyphosate (Roundup). ⁵⁵ Widestrike This Bt cotton plant contains a CryIF gene in addition to the cryIAC gene. This Bt variety was developed by Dow AgroSciences. ⁵⁶ Event-1xEvent-24 A cross between 2 Bt cotton crops carrying a cryIAC gene and a cryIEc gene respectively. GHB614 This line carries a 2mEPSPS gene, which protects the cotton plants against the herbicide glyphosate. The technology was developed by Bayer Cropscience. ⁵⁷

Sources:

CERA 2010. GM Crop Database (http://cera-gmc.org/index.php?action=gm_crop_database). Center for Environmental Risk Assessment (CERA), ILSI Research Foundation, Washington D.C., Grùere GP, Sun Y 2012. IFPRI Discussion Paper 01170 Measuring the Contribution of Bt Cotton Adoption to India’s Cotton Yields Leap. Available via <http://www.ifpri.org/sites/default/files/publications/ifpridp01170.pdf>
James C 2011. ISAAA Brief 43 Global Status of Commercialised Biotech/GM Crops: 2011, India, p. 51-87, International Service for the Acquisition of Agri-Biotech Applications (ISAAA).

49 Wilson F et al 1994. Yield, yield components, and fiber properties of insect-resistant cotton lines containing a *Bacillus thuringiensis* toxin gene. *Crop Sci* 34, 38-41.

50 Center for Environmental Risk Assessment (CERA), ILSI Research Foundation. GM Crop Database, MON531/757/1076.

51 Center for Environmental Risk Assessment (CERA), ILSI Research Foundation. GM Crop Database, Event-1

52 Genetic Rights Foundation. Biosafety Scanner. GFM. (<http://en.biosafetyscanner.org/schedaevento.php?evento=200>).

53 Center for Environmental Risk Assessment (CERA), ILSI Research Foundation. GM Crop Database, MON15985.

54 Metahelix Life Sciences Ltd. Bt Cotton – CryIC Highlights. Available via http://www.meta-helix.com/main/pbt_cotton/html

55 Center for Environmental Risk Assessment (CERA), ILSI Research Foundation. GM Crop Database, MON15985 x MON88913.

56 Dow Agro Sciences. Product Safety Assessment (PSA): Widestrike Insect Protection. Available via <http://www.dow.com/productsafety/finder/ws.htm>

57 Center for Environmental Risk Assessment (CERA), ILSI Research Foundation. GM Crop Database, GHB614.

A boost for the Indian economy

The “boom” in the cotton production has had a quantifiable positive impact on the Indian macro-economy. Today, India accounts for 21 % of the global cotton production. In 2002 – 2003 this figure was only 14 %. Since 2006, India has been the second largest producer of cotton – after China, but ahead of the United States. Furthermore, India converted its status from a net importer of cotton to a net exporter.²⁰

From importer to exporter

Cotton and textiles are important industries in India. According to the “Central Institute for Cotton Research” there are 8 million cotton farmers in India and a further 36 million Indians are employed in the cotton-processing industry and the textile industry. India has 1.7 million registered looms and 1500 official textile factories. Then there are also thousands of workshops and artisanal spinners, weavers and tailors.

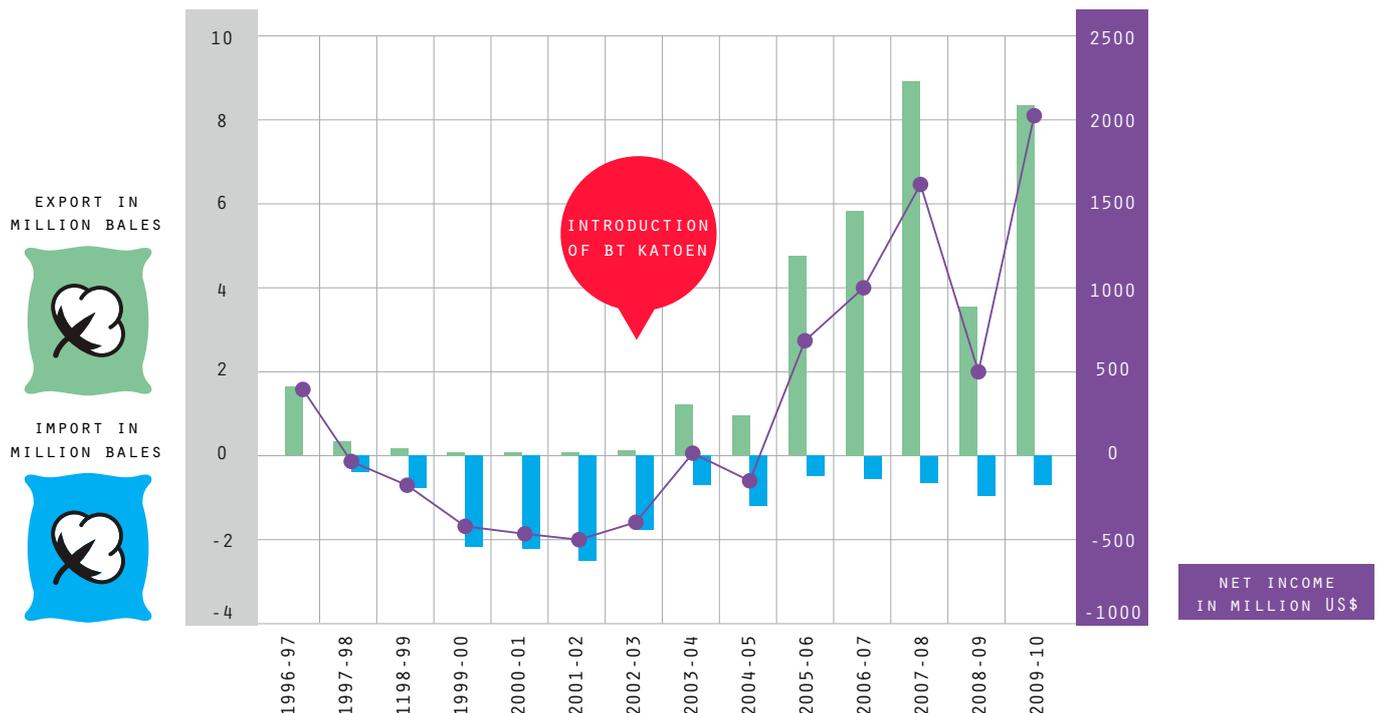
In order to supply these textile activities with raw materials, India used to import more cotton than it exported up to 2005.

However, India has grown into a net exporter. In 2009 – 2010 more than 8 million bales of 170 kg were exported, generating US\$ 2.3 billion in income. The import receded parallel to the increasing export (see figure 13).⁵⁸

This swing occurred so rapidly that the supply for the home market was threatened. Therefore, the Indian government temporarily limited the export. The export limitations were lifted again in the course of 2011.²⁰

FIGURE 13

THANKS TO BT COTTON, INDIA EVOLVED FROM AN IMPORTER INTO AN EXPORTER



58 The Cotton Corporation of India Ltd, Ministry of Textiles, Cotton imports and exports 1996 – 1997 onwards. Available via <http://www.cotcorp.gov.in/statistics.aspx?pageid=8#cotlon3>



Quality and quantity

The quality of Indian cotton increased together with the quantitative increase in production. Traditionally, India grew cotton varieties that produced short (< 20 mm), medium (20.5 – 25.5 mm) and medium length (25 – 27 mm) cotton fibers. Since the introduction of the new hybrid cotton seeds in the 1970s and Bt cotton in 2002 – 2003, the Indian farmer has focused increasingly on the production of long (27.5 – 32 mm) and extra long (> 32.5 mm) cotton fibers.⁵⁹ It is mainly these fibers that are used in the textile industry – both the international textile industry and the artisanal Indian tailor.

Whilst there were virtually no long cotton fibers produced in India in 1947, this figure rose to 38 % of the total production in 2002 – 2003 and 77 % in 2010 – 2011. The production increase in long cotton fibers is even more impressive in absolute figures: from 5.1 million bales in 2002 – 2003 to 26 million in 2010 – 2011.⁵⁹ Obviously these long fibers fetch a higher price at both the national and international cotton markets. To be absolutely clear, this shift towards qualitatively better fibers has nothing to do with the insect resistance of Bt crops, but is due to the choice of cotton variety.

A blossoming seed industry

In addition to cotton production, the Indian seed industry has also flourished as a result of the production of Bt cotton seeds. The total Indian biotech sector generates a turnover of US\$ 4 billion (2010 – 2011).²⁰ The turnover for the Indian biotechnology seed industry is estimated at US\$ 551 million. With a growth of

28 % compared to the previous year, the biotechnology seed industry is the strongest growing sub-sector of the Indian biotech industry. As cotton is the only permitted biotechnology crop in India, biotech cotton contributes the lion's share to this turnover and growth.²⁰

Textile fibers and so much more

Cotton means much more than just textile fibers for the Indian agricultural sector. For every kilogram of cotton fiber, the cotton sector yields 1.65 kilograms of cotton seed. This seed is rich in protein (23 %) and vegetable oil (21 %) and is an important food source for humans and animals.

Table oil

Unfortunately the nutritious cotton seed (obtained from both Bt and non-Bt cotton) cannot simply be used in human and animal food products. Cotton seeds contain gossypol. This substance is toxic to humans and affects the liver. Therefore, seeds are not eligible for human consumption.

This is a pity, as the current global cotton production would meet the daily protein requirements of 500 million people. Research has been conducted for several years to use biotechnology to find a way to reduce the production of gossypol in the plant.⁶⁰ For now these experiments remain limited to laboratory and field trials.

However, by pressing the cottonseeds, an oil can be extracted that is eligible for human consumption. This cottonseed oil has

gained increasing popularity in India over the last few years. According to the “All India Cottonseed Crushers’ Association” (AICOSCA), cotton has grown to become the second most important field crop for the production of table oil. In figures: in 2009 – 2010 the total Indian production of oil for consumption was 7.88 million tons, of which 1.08 million tons (13.7 %) was obtained from cottonseed. The AICOSCA predicts a production of 1.31 million tons of cottonseed oil for the period 2011 – 2012.⁶¹

The production volume could increase further if the seeds are peeled first and crushed more effectively. This would offer India the opportunity to become independent of the importation of edible oil.⁶¹

Animal fodder

Animal fodders based on cottonseed stand out because of their high protein content. However, the problem here remains the toxic substance gossypol. Non-ruminants – such as chickens and pigs – experience the same problems as humans. Ruminants can tolerate the substance, because it is broken down by the microorganisms in the stomachs of these animals.

Fodder based on cottonseed is therefore restricted to cattle and buffalo. The use of cottonseed cakes as fodder – de-oiled or not – has been on the up for several years in India. So strongly in fact, that cottonseed has now become the main ingredient (33 %) in processed fodder, followed in a distant second place by soy, rapeseed and ground nuts (see figure 14).²⁰

Research by the Indian “National Dairy Research Institute” has also revealed that cows show no preference for cakes

pressed from non-Bt cottonseed over Bt cottonseed cakes. The researchers also found that there was no difference in digestion, milk production, body condition and weight gain for animals fed Bt seed compared to non-Bt seed. The Bt protein is completely harmless to cattle, as it is broken down to its basic components just as all other proteins are. The Bt protein does not pass into the milk or blood of the animals.⁶²

Researchers from the “College of Veterinary Science” in Hyderabad confirm that animal fodders based on Bt cotton are equal in quality and have no harmful effects on animals. The blood values of sheep that received Bt cotton for three months did not differ in any way from sheep that were fed non-Bt cotton.⁶³

60 Sunilkumar G et al 2006. Engineering cottonseed for use in human nutrition by tissue-specific reduction of toxic gossypol. Proc Natl Acad Sci USA 103, 18054-18059.

61 All India Cottonseed Crushers’ Association (AICOSCA), 50th Annual Report & Accounts, 2009 – 2010.

Available via <http://www.webconnectindia.net/aicosca1/files/50th%20Annual%20Report%20&%20Accounts%202009-10.pdf>

62 Mohanta RK et al 2010. Nutritional evaluation of transgenic cottonseed in the ration of lactating dairy cows. Trop Anim Health Prod 42, 431-438.

63 Anilkumar B et al. Sero-biochemical studies in sheep fed with Bt cotton plants. Toxicol Int 17, 99-101.

FIGURE 14A

COTTONSEED OCCUPIES THE GREATEST PROPORTION IN CATTLE FODDER CAKES IN INDIA (2007 - 2008)

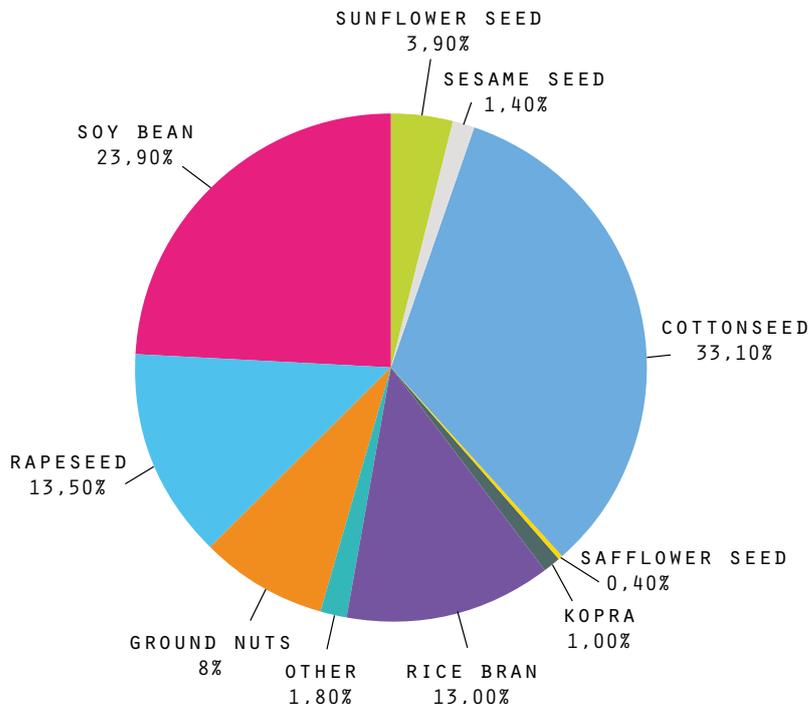
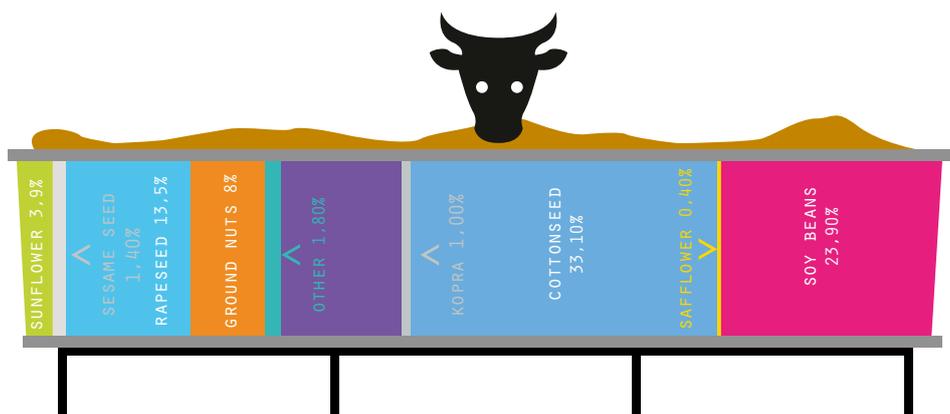


FIGURE 14B

ALTERNATIVE REPRESENTATION OF THE COMPOSITION OF CATTLE FODDER CAKES IN INDIA (2007 - 2008)



BT COTTON IN OUR DAILY LIVES



Over 80 % of the global cotton cultivation now consists of Bt cotton. Bt cotton is resistant to being eaten by certain insects, but the cotton fiber itself has not been altered. The cotton fiber is primarily used in the production of textiles. One of the most famous examples is denim jeans, a lesser known application is our Euro notes. These too contain cotton. As over 80 % of the global cotton production is Bt cotton, we are certain to come into daily contact with it. And primarily via our clothing. Only certified organic cotton is free of Bt cotton.

In addition to cotton fiber, the cottonseed also has various uses. The oil that it contains is used in cosmetic products and in certain food products. The “pressed cake” that remains after the oil has been extracted is sometimes processed in animal feed. Bt proteins can be found in the seed and the pressed cake of Bt cotton, but not in the oil. The European Union allows the import of certain varieties of Bt cotton and the processing in human food and animal feed.⁶⁴ If a product derived from Bt cotton is processed in human food or animal feed, this must be stated on the label.

Resistance, a possible Achilles heel

The greatest limitation of Bt technology is that caterpillars will eventually develop resistance to the Bt toxin. Bollworms that are no longer susceptible to the Bt toxin could spread across cotton plantations in a short period and cause the same damage as was seen in the days prior to Bt technology. In order to prevent this, India is increasingly opting for Bt crops that offer a double protection against bollworms because they produce two different toxins (mainly Bollgard II cotton to date).

First resistance in the field

The occurrence of resistance to a certain immune system has nothing to do with genetic modification. The development of resistance is a natural selection process whereby insects, bacteria, plants, etc. try to adapt to a changing environment. When Bt crops are cultivated indiscriminately and on a large scale, the selection pressure on Bt-sensitive insects will increase. This can lead to the emergence of bollworms that are resistant to the Bt insecticide. This is a nightmare scenario for a Bt cotton farmer. As with their predecessors in previous decades, Bt resistant insects could decimate the cotton fields once more. Cotton farmers would have to start spraying large quantities of insecticides again. All would then have been in vain. This doom scenario could become more than just a theory. The bollworm has demonstrated in the past that it is a champion at adapting to chemical pesticides. Furthermore,

scientists have already succeeded in culturing bollworms in the laboratory that are resistant to a Bt toxin⁶⁵. Experts have wondered for some time how long it would take before the first Bt-resistant bollworms would surface in the field.

Scientists from Monsanto – the company that first commercialized the Bt technology – discovered the first resistant bollworms in Indian Bt cotton fields in 2009.⁶⁶ This was a limited area in the Indian province of Gujarat. The discovery was later confirmed by scientists from the “Indian Agricultural Research Institute” in New Delhi.⁶⁷



65 Tabashnik B et al 2003. Insect Resistance to Transgenic Bt Crops: Lessons from the Laboratory and Field. *J Econ Entomol* 96, 1031-1038.

66 Bagla P 2010. Hardy Cotton-Munching Pests Are Latest Blow to GM Crops. *Science* 327, 1439.

67 Dhurua S, Gujar GT 2011. Field-evolved resistance to Bt toxin CryIAC in the pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), from India. *Pest Manag Sci* 67, 898-903.

Second generation Bt cotton

The resistance of the insects is limited to first generation Bt cotton, the so-called “Bollgard I” cotton. This variety carries only one toxin gene, *Cry1Ac*. The bollworms displayed no resistance to second generation Bt cotton – the “Bollgard II” hybrids – that carries two different toxin genes.

This is also key to avoiding resistance: the sowing of varieties that carry two or more toxin genes, which significantly raises the bar for the insects to acquire resistance.

These “double Bt” varieties – based on Bollgard II technology – were introduced in India in 2006. At the time they represented only 4 % of the total Bt cotton area (see figure 15). Since then, almost 8.7 million ha have been cultivated with these varieties, or 82 % of the complete Bt cotton area.⁶⁸ At the same time, field trials are currently being set up in India with Widespread and Event-1xEvent-24 varieties. These plants also carry two different Bt toxin genes (see section on “Bt cotton and the Indian government – chronology”).

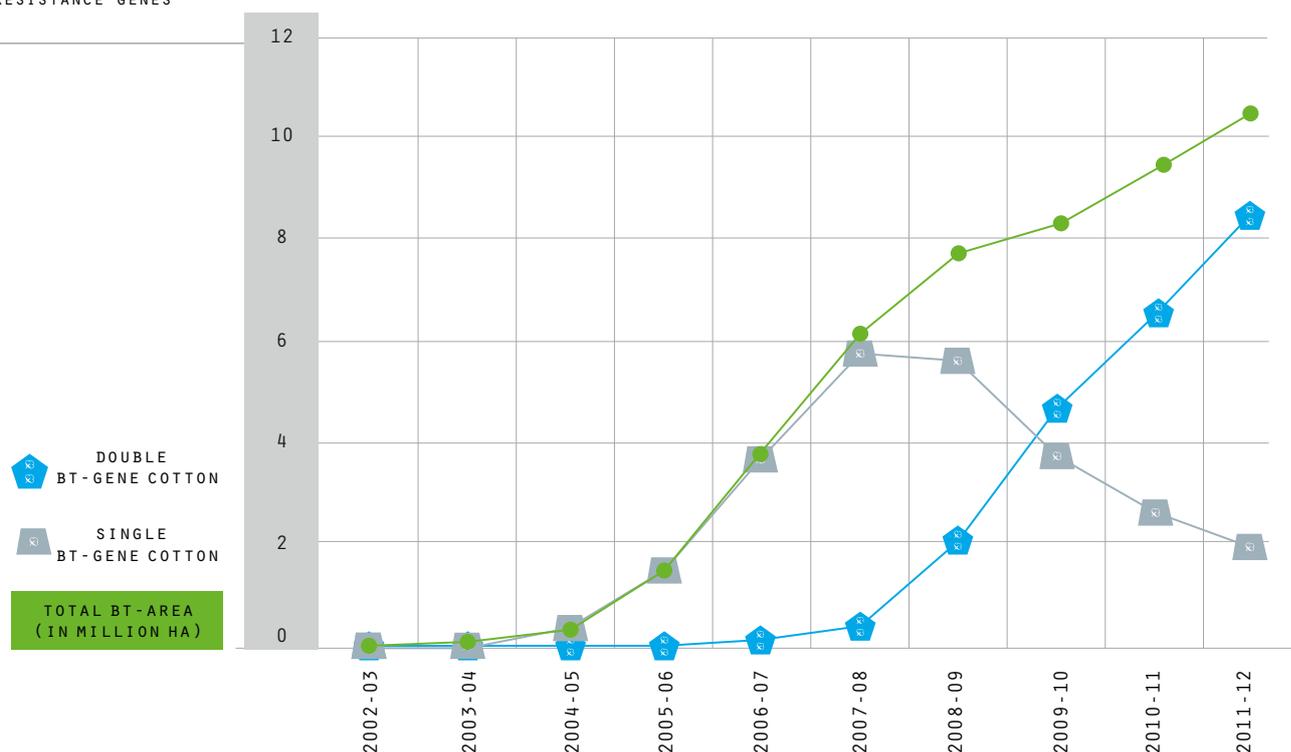
In addition, there are also other measures that can limit the development of resistance in plague species. As long ago as 1998, the US Environmental Protection Agency (EPA) was working on a number of rules for the management of insect resistance against Bt toxins.⁶⁸ These include the extensive

execution of field trials on the biology of plague species, the careful monitoring of resistance or increased tolerance with regards to Bt toxins in the field, the provision of information and education to farmers, having an action plan in place in case resistance occurs and setting up a rapid communication and information network between farmers, seed retailers, scientists, government and the public.

There are also more technological measures that can be taken to combat resistance. A key element in the EPA’s strategy is the planting of refuge crops between the Bt crops.⁶⁸ These non-Bt refuge crops ensure that there are always some Bt-sensitive insects present in or near the Bt field. If these Bt-sensitive insects mate with resistant insects, the resistance will be diluted in the next generation (see section on “Forming a dam against resistance”). American scientists recently achieved success with a similar method. They released adult sterile pink bollworms (*Pectinophora gossypiella*) and were thus able to slow down the development of resistance in the state of Arizona (USA) (see section on “Forming a dam against resistance”).⁶⁹

FIGURE 15

BT COTTON WITH ONE RESISTANCE GENE IS REPLACED BY BT COTTON WITH 2 RESISTANCE GENES



68 United States Environmental Protection Agency (US EPA). EPA’s Regulation of *Bacillus thuringiensis* (Bt) Crops. Available via <http://www.epa.gov/opppbd1/biopesticides/pips/regofbt crops.htm>

69 Tabashnik BE et al 2012. Sustained susceptibility of pink bollworm to Bt cotton in the United States. *GM Crops Food* 3, 194-200.



The “dose rule” forms a cornerstone in the management of Bt-resistant insects. The rule states that Bt plants must contain a sufficiently high dose of Cry proteins to kill the overwhelming majority (> 99 %) of bollworms. If the dose is too low and certain bollworms are able to survive a Bt meal, they will develop into moths that can mate with each other. These eggs will then produce new resistant caterpillars. In that case, a cotton field would be full of Bt-resistant caterpillars in no time at all.

The “stacking rule” demonstrates that the risk of resistance can be reduced drastically by stacking two toxins with a different mode of action in 1 plant. If a bollworm develops resistance to one toxin – through a (spontaneous) mutation in its genetic material – the worm will still be sensitive to the other toxin. This means that the worm will still be killed and the acquired resistance will disappear from the population. Of course an insect could always acquire resistance to 2 toxins simultaneously, but this risk is very low. If the risk of acquiring resistance to 1 toxin is set at 1 in 100,000, then the risk of resistance to 2 toxins simultaneously would be 1 in 10 billion.

In addition, there is also the “refuge rule”. In the USA, the US Environmental Protection Agency (US EPA) asks farmers who grow Bt cotton or Bt corn to sow strips of non-Bt crops next to their Bt fields. Bollworms are able to survive on these plants (termed “refuge crops”). The aim is that there will always be enough “healthy” Bt-sensitive moths present in or near the Bt field. Any moths that have become resistant in the Bt field can then mate with the Bt-sensitive moths present in the refuge crops. As Bt resistance is a genetically recessive characteristic, the offspring of such a cross will be Bt-sensitive. If these eggs are deposited on a Bt plant, the larvae will die after eating a Bt meal and the resistance will disappear from the field.

The release of sterile adult insects aims to achieve a similar scenario.⁷⁰ These insects are grown in the laboratory, after which they are irradiated so that they can no longer produce offspring. The sterile insects are then released in the fields in large numbers. Due to the large number of sterile moths, any moths that have become resistant in the Bt field will initially mate with the sterile, released moths. In this case, no offspring will be produced, resulting in the resistance dying a quiet death. Up to 2 billion sterile *Pectinophora gossypiella* moths (pink bollworm) were released in the cotton fields of the state of Arizona between 2006 and 2009 (or 25,000 sterile moths per ha per year). The eradication program was successful: in 2009, only 2 larvae were counted in 16,600 cotton balls, compared to 2550 larvae in 2005. The infection grade decreased from 15.3 % to 0.012 %, which is a 99.9 % reduction. A similar decrease was seen in the number of moths counted every week in the insect traps.⁷⁰

70 Tabashnik BE et al. 2010. Suppressing resistance to Bt cotton with sterile insect releases. Nat Biotechnol 28, 1304-1307.

Effect on the health of humans and the environment

To what extent has Bt cotton contributed to the health of humans and the environment? The use of pesticides definitely decreased following the introduction of Bt cotton, with an extremely positive impact on the health of the cotton farmer. Academic and government research also points out that Bt cotton has no negative effects and causes no fundamental changes to the environment and the biodiversity when compared to non-Bt cotton. However, Bt cotton is still a crop that requires a lot of water. In that regard, Bt cotton places the same burden on the environment as non-Bt cotton.

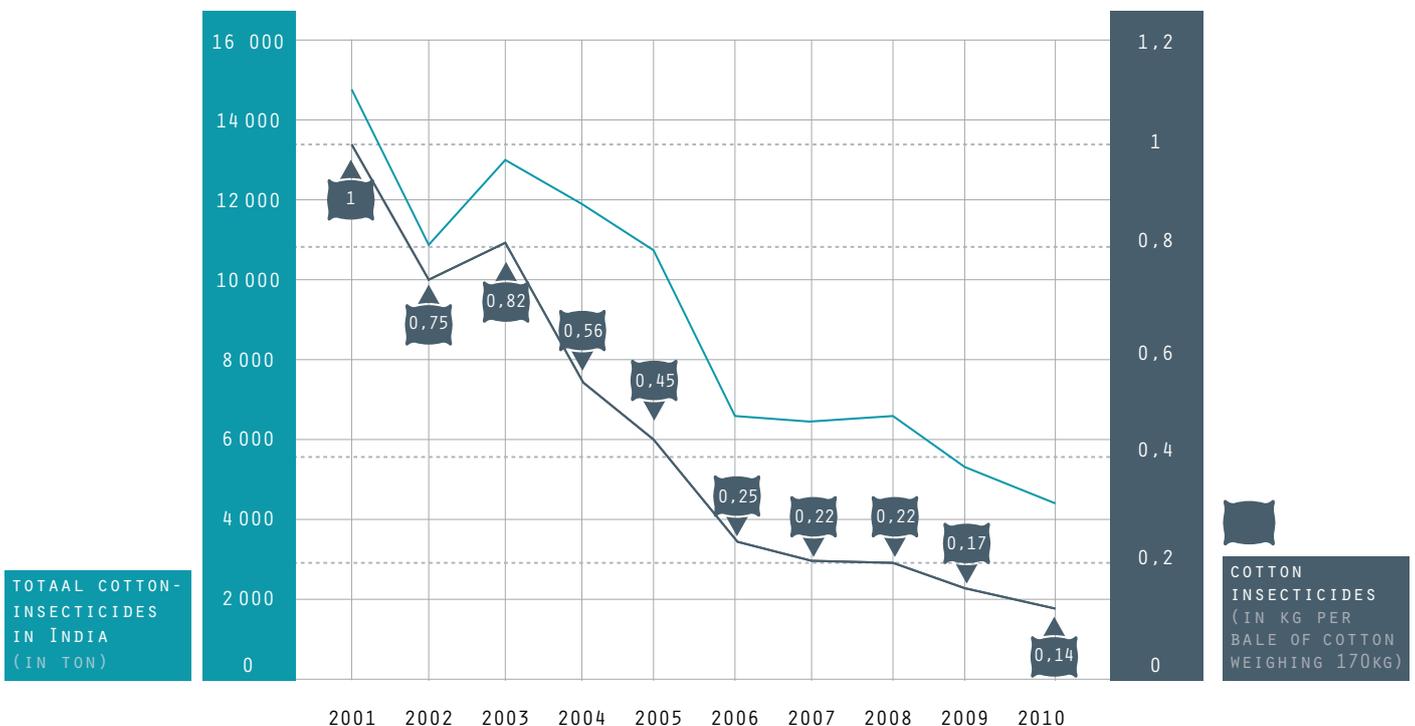
Less spraying

The bollworm is still enemy number one for the Indian cotton farmer. Traditionally, the cotton industry in India used large amounts of pesticides. In 2001, the use of insecticides in the cotton industry accounted for 33 % of all pesticide use in India. This figure decreased dramatically following the introduction of Bt cotton. First to 17 % in 2006 and then to 11 % in 2010.²⁰ As these figures only reflect the position of the cotton industry

compared to other crops, this can create a distorted image. Therefore, it is better to look at the absolute figures. The use of pesticides in India decreased from 47,020 tons in 2001 – 2002 to 41,822 tons in 2009 – 2010.^{71,72} The absolute use of insecticides in the cotton industry has therefore decreased from an estimated 14,950 tons in 2001 to 4,600 tons in 2010 (see figure 16), which is a decrease of 30 %.

FIGURE 16A

IN CONTRAST TO THE LIMITED DECREASE IN THE TOTAL USE OF PESTICIDES IN INDIA (FIGURE 16B), THE BT TECHNOLOGY HAS RESULTED IN A SPECTACULAR DECREASE IN THE USE OF INSECTICIDES IN THE COTTON FIELDS.

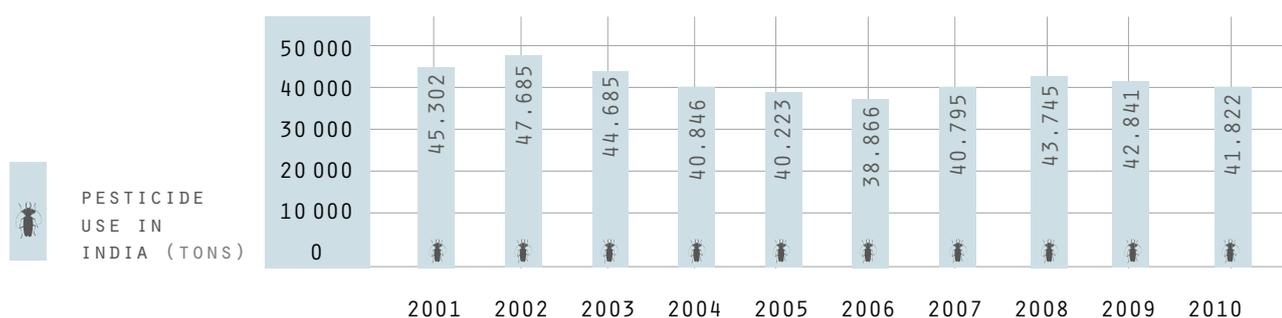


71 Lok Sabha 2010. Requirement of Fertilizers/Pesticides, Unstarred question No. 3433, Lok Sabha, the parliament of India.

72 Central Insecticides Board and Registration Committee (CIBRC). 2011. Ministry of Agriculture, Government of India. <http://cibrc.nic.in/>

FIGURE 16B

THE TOTAL USE OF PESTICIDES IN INDIA



When factoring in the increase in cotton area, we come to a remarkable conclusion. Our own calculations reveal that 1.73 kg of pesticides (active ingredient) were used per hectare in 2001. This quantity decreased significantly with the introduction of Bt cotton to 0.74 kg/ha in 2006 and 0.43 kg/ha in 2010. If we include the increased production in the calculations this means that 5.9 g of pesticides was required for the production of 1 kg of cotton in 2001, whilst this decreased to 1.5 g in 2006 and less than 0.9 g in 2010. This seven-fold decrease in the use of pesticides illustrates very clearly that the introduction of Bt cotton has made the cotton industry in India much more environmentally friendly.

Unfortunately an insecticide-free cotton industry will remain a utopia for the foreseeable future, as cotton plants have other pests in addition to the bollworm. These other pests are not sensitive to Bt toxins. Therefore, the spraying of insecticides is still necessary to keep these insects in check. Nonetheless the use of insecticides in the cotton industry has decreased significantly since the introduction of Bt cotton. A recent study by Shahzad Kouser and Matin Qaim demonstrates that not only the cotton farmer's wallet profits, but also his health.⁷³ The risk of pesticide poisoning amongst Bt cotton farmers has decreased by 88 % (from 1.6 poisonings per season per farmer to 0.19) compared to farmers who grow conventional cotton. The frequency of poisoning amongst Indian farmers is so high because most farmers spray manually without protective clothing. Less frequent spraying results in less exposure to potentially toxic chemicals.

According to the authors, "Bt cotton in India reduces the number of pesticide poisoning cases by 2.4 million per year and this saves US\$ 14 million in healthcare costs and absenteeism." They are also of the opinion that their estimates are conservative.⁷³ Less conservative models estimate that 9 million cases of poisoning are avoided, with a saving of US\$ 51 million.

73 Kouser S, Qaim M. Impact of Bt cotton on pesticide poisoning in smallholder agriculture: A panel data analysis. *Ecological Economics*. 2011 September 15:70 (11):2105-13

Soil chemistry and microbiology

In addition to the effect of Bt crops on the health of humans, there is also the social debate about the effect of biotech crops on the environment and biodiversity. Questions include: To what extent do biotech crops alter agricultural and natural biotopes? Do they reduce the natural microbiological diversity of the soil? Do they alter the (bio)chemical composition of the soil in a negative way? This is without doubt an important topic that applies to all biotech crops and should not be seen merely in the context of Bt cotton in India. In this overview, we will present a number of recent studies by academic and government centers that discuss these questions specifically with regards to Bt cotton.

Scientists from the “Indian Agricultural Research Institute” (IARI) in New Delhi (India) and the “Centre for Environmental Risk Assessment and Remediation” (CERAR) of the University of South Australia concluded that Bt cotton has no negative effects on a series of biological and biochemical soil parameters when compared to conventional cotton.⁷⁴ The parameters that were studied included microbiological biomass and diversity, total organic fraction and a series of soil enzyme activity assays.

Whereas the abovementioned study was conducted on plants grown in a glasshouse, scientists from the “Institute of Microbial Technology” (CSIR) in Chandigarh confirmed these findings in a field trial. They found that Bt cotton – when compared to conventional cotton – did not alter the dynamics of microbial communities in the field.⁷⁵ The Indian scientists from the IARI also concluded that Bt cotton has no negative effects on the soil, as long as the farmers apply good agricultural

practices⁷⁶. This includes the principle of crop rotation and/or combined planting, in addition to the regular use of organic fertilizers instead of urea fertilizers.⁷⁶ However, such good agricultural practices apply to all crops, with or without Bt technology.

The three abovementioned research teams all reached the same conclusion independently: Bt cotton does not promote or hinder sustainable agriculture any more than conventional cotton.



Cotton flowers and apiculture

When cultivating plants that protect themselves against plague insects, it is very important to determine their effect on useful insects. Especially if at least one third of all crops depend on insects for effective pollination.⁷⁷

Taking into consideration the specific action of the various Cry proteins, it is very unlikely that pollen from the currently licensed Bt crops will affect the vitality of useful insects such as honeybees. Nevertheless, bees rightly deserve a lot of attention in the Bt story. Honeybees are responsible for up to 80 % of all

pollination activities⁷⁷ and also come into direct contact with the Cry proteins by consuming large quantities of pollen.

The many studies that have been performed to date appear to confirm the specificity of the Cry proteins. Field studies of Bt cotton (Cry1Ac) during the 2003 – 2004 and 2004 – 2005 seasons demonstrated that there were equal numbers of bees in Bt fields and non-Bt fields.⁷⁸ More detailed studies using Bt pollen collected from the field that examined the effect on vitality and weight of bees also indicate that Bt pollen does not differ from conventional pollen.^{79,80,81} Robyn Rose and Jeff

74 Sarkar B et al 2009. Assessment of biological and biochemical indicators in soil under transgenic Bt and non-Bt cotton crop in a sub-tropical environment. *Environ Monit Assess* 156, 595-604.

75 Kapur M et al 2010. A case study for assessment of microbial community dynamics in genetically modified Bt cotton crop fields. *Curr Microbiol* 61, 118-24

76 Singh RJ et al 2013. Effects of transgenic Bt cotton on soil fertility and biology under field conditions in subtropical inceptisol. *Environ Monit Assess* 185, 485-495.

77 Klein A-M et al 2007. Importance of pollinators in changing landscapes for world crops. *Proc R Soc B* 274, 303-313.

78 Hof's JL et al 2008. Diversity and abundance of flower visiting insects in Bt and non-Bt cotton fields of Maputaland. *Inter J Trop Insect Sci* 28, 211-219.

Pettis of the United States Department of Agriculture (USDA), together with entomologist Galen Dively from the University of Maryland (USA) went one step further and checked the effect of Bt corn pollen on a long list of parameters. They checked the weight of the bees, the orientation, the learning ability, the quantity of pollen collected, the activity of the pollen collectors, the health of the colony and the weight and development of the brood. There were no indications that the bees behaved differently as a result of eating Bt pollen compared to control pollen.⁸¹ Chinese scientists used a tube maze to demonstrate that the pollen of Bt cotton (CryIAc) has no negative effect on the learning ability of bees.⁸² The finding that bees are not killed by Cry proteins was confirmed by laboratory data. Various studies, including a meta-analysis based on 25 different studies, demonstrate that Cry proteins – that are effective against the larvae of moths and

beetles– have no negative effect on the survival of bee larvae or adult honeybees.^{79,80,83} In addition, these studies often use concentrations of Cry proteins that are more than 10 times higher than the concentrations found in the field.⁸³ The global reported decline in bee colonies is more likely to be the result of other factors^{81,84} than the cultivation of Bt crops.

The use of insecticides in the Indian cotton fields has reduced significantly due to the cultivation of Bt cotton.²⁰ According to entomologists from the “Indian Agricultural Research Institute”, beekeepers in the provinces of Haryana, Rajasthan and Punjab are therefore motivated to place their bee colonies in Bt cotton fields. These beekeepers produce normal quantities of honey, receive a good market price and have not reported any negative effect of Bt cotton on their bee populations.⁸⁵

Effect of Bt cotton on non-target insects

If one looks at the general effect of Bt crops on other non-target insects, the message is less clear than for bees. The effect appears to depend on the crop and the insect and is almost always an indirect effect of the reduced use of insecticides.

In 2007, the journal *Science* published a meta-analysis that used 42 field experiments and that included a broad range of non-target insects.⁸⁶ The American scientists concluded that – depending on the crop – certain non-target organisms were less abundant in Bt fields compared to insecticide-free control fields. This was the case for Bt cotton (CryIAc), but not for Bt corn. Logically, the Bt cotton fields contained fewer insects that are sensitive to the specific Cry protein, but there were also slightly fewer insects from other families. However, in the latter case the scientists could not demonstrate that the reduced presence was due to a direct toxic effect or due to reduced presence of Bt-sensitive prey insects. A more recent analysis that included 21 extra field trials reached the same conclusion.⁸⁷ However, both meta-analysis studies are very clear in the comparison of Bt fields to insecticide treated non-Bt fields: many more useful insects are found in the Bt fields.^{86,87}



79 Liu B et al 2005. The impacts of the pollen of insect-resistant transgenic cotton on honeybees. *Biovers Conserv* 14, 3487-3496.

80 Hendriksma et al 2011. Testing pollen of single and stacked insect-resistant Bt maize on in vitro reared honey bee larvae. *Plos One* 6, e28174.

81 Rose R et al 2007. Effect of Bt corn pollen on honey bees: emphasis on protocol development. *Apidologie* 28, 368-377

82 Han P et al 2010. Use of an innovative T-tube maze assay and the proboscis extension response assay to assess sublethal effect of GM products and pesticides on learning capacity of the honey bee *Apis mellifera* L. *Ecotoxicology* 19, 1612-1619.

83 Duan JJ et al 2008. A meta-analysis of effect of Bt crops on honey bees. *Plos One* 3, e1415.

84 Gill et al 2012. Combined pesticide exposure severely affects individual and colony level traits in bees. *Nature* doi:10.1038/nature11585.

85 Dhillon MK et al 2011. Impact of Bt cotton on insect biodiversity in cotton ecosystems in India. *Pakistan Entomologist* 33, 161-165.

86 Marvier M et al 2007. A meta-analysis of effects of Bt cotton and maize on nontarget invertebrates. *Science* 316, 1475-1477.

Strangely enough, the reduced use of insecticides in Bt cotton fields can have a negative effect in certain conditions. Based on a 10-year field trial in the North Chinese province of Heibei, Chinese scientists noted a steady increase in the population of mirid bugs in Bt cotton fields.⁸⁸ These mirid bugs are sensitive to the broad-spectrum insecticides used in conventional cotton farming against the bollworm. However, the reduced use of insecticides in Bt fields relaxes the control over the bugs and as a result they can grow into a secondary plague. Paradoxically, this study illustrates the power of Bt crops: the Cry proteins are specific, which means that the mirid bugs are not killed and because lower levels of insecticides are used in Bt fields, the population is less efficiently controlled.

All these studies into the effects of Bt crops on non-target organisms illustrate once again that Bt crops should be seen as part of an integrated pest management system. They should only be used if a Bt-sensitive insect forms a plague for the crop and they should never be viewed as the total solution. When used, they offer an environmentally friendly alternative to chemical pest control.



Bt as unexpected support for organic farming

The confirmation that Bt crops ensure greater diversity of insects in comparison to the conventional crop cultivation was also confirmed by scientists from the Chinese “Academy of Agricultural Sciences” in Beijing and the French “National Institute for Agricultural Research” (INRA). They performed measurements at 36 locations in 6 provinces in northern China with 10 to 20 field trials per location.⁸⁹ The results of the study were particularly convincing. The scientists observed a steady increase of various insects (including lady-birds and lacewings) and spiders in the Bt cotton fields. As these useful insects are the natural enemies of various pest insects, this allows a better control of other non-Bt sensitive pests. The scientists attribute this increase in natural enemies solely to the reduced use of broad-spectrum insecticides. Furthermore, a positive spill-over effect was observed for the neighboring non-biotech crops.⁸⁹ The monitored northern Chinese areas also contained more natural predators in the surrounding corn, ground nut and soy fields, leading to natural pest control and a reduction in the need to spray there too. A study by the same scientists shows that the same applies to the bollworm.

From 1997 to 2006, there was a steady decrease of bollworm eggs and larvae in Bt fields of the Chinese trial fields. A remarkable observation was that there were also fewer larvae present in neighboring non-Bt fields.⁹⁰ For their analysis, the scientists considered all environmental factors and concluded that the introduction of Bt cotton was primarily responsible for the reduced presence of the bollworm in neighboring non-Bt fields.

In other words: the Bt technology does not necessarily have to be at odds with organic farming. On the contrary, biotechnology can offer significant support to an agricultural model which uses fewer chemical pesticides and is focused more on biological pest control.

87 Naranjo SE et al 2009. Impacts of Bt crops on non-target invertebrates and insecticide use patterns.

CAB reviews: Perspective in agriculture, veterinary science, nutrition and natural resources 4.

Available via <http://fbae.org/2009/FBAE/website/images/pdf/important-publication/impacts-of-bt-crops-on-non-target-invertebrates-and-insecticide-use-patterns.pdf>

88 Lu et al 2010. Mirid bug outbreaks in multiple crops correlated with wide-scale adoption of Bt cotton in China. *Science* 328, 1151-1154.

89 Lu et al 2012. Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services. *Nature* 487, 362-365.

90 Wu K-M et al 2008. Suppression of cotton bollworm in multiple crops in China in areas with Bt toxin-containing cotton. *Science* 321, 1676-1678

Biotech cotton beyond India

With 24.2 million ha, biotech cotton –after soy and corn – is the third most frequently cultivated biotech crop in the world. With a growth of 18 % in one year (between 2010 and 2011) it is the fastest growing biotech crop.²⁰



In 2012, biotech cotton was cultivated in 15 countries. Four of these countries grow more than one million ha of biotech cotton. These are, in decreasing order, India (10.8 million ha), the United States (4.4 million ha), China (4.0 million ha) and Pakistan (2.8 million ha). The other 11 biotech cotton countries are Argentina, Brazil, Australia, Myanmar, Burkina Faso, Mexico, Colombia, South Africa, Sudan, Paraguay and Costa Rica.¹⁹

Australia is the absolute leader concerning adoption. Australia grows 520,000 ha of biotech cotton, which corresponds to 99.5 % of all cotton in Australia. In the United States, 4.4 of the 5.0 million ha of cotton is biotech cotton, which corresponds to 88 %. Biotech cotton is also gaining popularity in countries such as Burkina Faso. Bollgard II cotton was introduced in 2008 on an area of 8500 ha and four years later this figure had increased to 310,000 ha.¹⁹

Meanwhile, a number of countries also cultivate biotech crops in which the insect resistance is combined with herbicide tolerance. The USA and Australia are among countries that have introduced the next generation biotech cotton, which offers protection against caterpillars (Bt cotton) and is also herbicide tolerant (so-called Roundup Ready Flex cotton).¹⁹

An estimated 24.3 million ha of biotech cotton was cultivated globally in 2012. Based on the latest FAO STAT data, this corresponds to 80 % of the entire cotton area.¹⁹ With a growth of 18 %, biotech cotton is the strongest growing biotech crop. During the period from 1996 to 2011, biotech cotton has resulted in a cumulative increased yield of 32.5 billion US dollars. In 2011 alone, biotech cotton was responsible for an increase in income for farmers of 6.7 billion US dollars.¹⁹



VIB