Ind. Jn. of Agri. Econ.
Vol.67, No.3, July-Sept. 2012

Economic and Environmental Impact of Bt Cotton in India

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I

COTTON IN INDIA

India is the largest cotton cultivating country in terms of acreage and second largest in terms of production in the world. India accounts for 34 per cent of the cotton area and 20 per cent of the cotton production in the world. But India ranks only 46th in terms of productivity with a yield of about one tonne per hectare (FAO, 2011). The yield of cotton is one of the lowest among the leading cotton producing countries in the world. The other major cotton producing countries in the world are China, USA and Pakistan. In India there are about nine mega cotton growing states with more than one lakh hectare area under cotton in 2008-09. Of the total cotton area, two states, Maharashtra and Gujarat, alone account for nearly 58 per cent of the cotton area in the country. In terms of production Gujarat alone accounts for nearly 32 per cent of the cotton production in the country though it has only 25 per cent of the cotton area. It is because of high productivity of cotton in Gujarat. Gujarat ranks third in terms of productivity in the country after Punjab and Haryana. On the other hand, Maharashtra with 33 per cent of the area accounts only for 21 per cent of the cotton production because of low productivity. The productivity of Maharashtra is one of the lowest in the country. Tamil Nadu has a comparatively lower share in production but ranks fourth in terms of productivity in India. Cotton is predominantly grown as a rainfed crop in India. About 64 per cent of the cotton crop in the country is grown without irrigation. The extent of irrigation varies widely across states, with Punjab growing the entire cotton crop under irrigation and Maharashtra growing nearly 95 per cent of the crop under rainfed condition. At the all India level only 36 per cent of the cotton crop is irrigated.

II

COMMERCIALIZATION OF AGRICULTURAL BIOTECHNOLOGY IN INDIA

Over the last fifteen years, modern agricultural biotechnology has been adopted rapidly at the global level, including several developing countries. This trend has

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been most apparent for genetically modified (GM) crops. This is the fastest diffusion of any new crop technology in the history of humankind (Qaim, 2005). The number of countries growing biotech crops has increased steadily from 6 in 1996, the first year of commercialisation, to 18 in 2003 and 29 in 2010. The growth rate between 1996 and 2010, the 15th anniversary of the commercialisation of biotech crops, was an unprecedented 87-fold increase making it the fastest adopted crop technology in recent history. In India 6.3 million small farmers benefited from planting 9.4 million hectares of Bt cotton, equivalent to a high adoption rate of 86 per cent (Clive, 2010). In India efforts to harness genetic engineering technology for boll worm resistance in cotton began in the 1990s with the import of genetically modified cotton and initiation of research programmes in national laboratories (APCoAB, 2006). The first approval of commercial cultivation of Bt cotton in India was granted in 2002 to three Bt cotton hybrids, MECH-12, MECH-162 and MECH-184, developed by the seed company Mahyco following a series of trials approved by the Government of India. In the first year of Bt cotton commercialisation in India, only three Bt hybrids had been approved, which were grown on large areas in different regions. Since these hybrids were not well adapted to all environments, the productivity advantage associated with the Bt gene was partly offset by general germplasm disadvantages in some locations (Qaim *et al.,* 2006). The crop failure along with other concerns has led to an intense scientific debate and public controversy. Much of this controversy surrounds ethical arguments, or concerns for multinational control of the world's seeds, human health, or environmental risk (Herring 2007a, b).

Technological development and dissemination is not an isolated scientific activity; rather it is embedded in and influenced by the social, economic, cultural and political conditions. This holds true for modern biotechnology also. As the wider global society struggles to come to terms with the benefits and (unknown) risks of the biotechnology, better understanding of consumer interests and concerns is needed to formulate and implement effective private and public policies (Onyango *et al.,* 2004). Factors influencing consumer preferences for bioengineered crops include their perceptions of benefits and risks of bioengineered crops on human health and the environment, their ethical stance toward genetic engineering, and their trust in government regulations concerning risk assessment and management (OECD, 2000). Hence a successful biotechnological programme needs to address the socio-economic issues, biosafety aspects, intellectual property management, etc. to ensure that public and policy makers are equipped to make informed choices. Analysing the socio-economic impacts of this new technology is important in the context of India emerging as one of the leading countries with large acreages under biotech crops. Currently (in 2010) India with 9.4 million hectares under Bt cotton is the fourth largest country in terms of acreage of biotech crops in the world after USA (66.8 mha), Brazil (25.4 mha) and Argentina (22.9 mha). Also out of the 15.4 million biotech farmers in the world, 6.3 million are in India. When the study was conducted in 2007-08 Bt cotton was the only GM crop approved for commercial cultivation in

India and all the biotech farmers in India were cotton farmers. In the above scenario this study addressed issues like reduction in pesticide use, increase in yield and income, profitability, gender dimension and environmental consequences of Bt cotton technology in India.

III

METHODOLOGY

A. *Sampling Procedure*

The study was conducted through survey method. The data for the study was collected from farmers through an interview schedule. The farmers were selected through a multistage stratified sampling procedure to select a representative sample at each stage. In the first stage, four states were selected considering the area, production, productivity and the spread of Bt technology. Accordingly, the States of Maharashtra, Gujarat, Andhra Pradesh and Tamil Nadu were selected for the study. In the next stage, the major cotton producing districts/regions were identified following the same criteria as used for selecting the States. For the purpose, districts wise area under cotton for each State was collected from the State Department of Agriculture/State Agricultural Universities/Department of Economics and Statistics. From each district, two major cotton growing taluks/blocks, and from each taluk/block three to five villages were identified considering the area under cotton and spread of Bt technology in consultation with the Agricultural Development Officers/Staff of State Agricultural Universities in the respective States. In all, 120 farmers were selected at random from each State comprising 80 Bt cotton growers and 40 non Bt cotton growers, making an aggregate sample size of 480 farmers from four States. The survey was conducted during 2007-08. State wise sample distribution is given below.

(i) *Gujarat*

Gujarat is the largest cotton producer in India, and stands second in terms of area under cotton. Surendranagar district alone cover 21 per cent of the total cotton area in the State, while Bhavnagar (11.17 per cent), Rajkot (10.99 per cent), Vadodra (8.86 per cent), Ahmedabad (8.47 per cent), Amreli (7.37 per cent) and Bharuch (7.36 per cent) are the other major cotton growing districts. Surendranagar and Rajkot districts were selected based on the procedure discussed in the methodology and 120 Bt and non-Bt farmers were contacted at the village level as detailed in Table 1.

(ii) *Maharashtra*

Maharashtra is the second largest producer of cotton though it ranks first in terms of area with 3.15 million ha under cotton. The productivity of cotton in Maharashtra is one of the lowest among the major cotton producing States in the country. In Maharashtra, nearly 38 per cent of cotton is cultivated in Amravati division followed by Nashik and Latur divisions. From the Amravati region Amravati and Yawatmal districts are the major cotton growing districts.

TABLE 1. VILLAGE WISE DISTRIBUTION OF SAMPLE FARMERS IN GUJARAT

District	Block	Villages	No. of farmers
(1)	(2)	(3)	(4)
Surendranagar (60)	Halvad	Mayurnagar	10
		Juna Devalia	10
		Nava Devalia	10
	Vadhvan	Moolchand	10
		Bhadresh	10
		Bakarthali	10
Rajkot (60)	Doraji	Torania	10
		Naniparabadi	10
		Motiparabadi	10
	Upleta	Motipaneta	10
		Hariyasan	10
		Kharachiya	10
Total			120

The selected blocks and villages and number of farmers contacted from each village are given in Table 2. In each village, ten respondents were contacted comprising both *Bt* and non-*Bt* cotton growers.

TABLE 2. VILLAGE WISE DISTRIBUTION OF FARMERS IN AMRAVATI AND YAWATMAL DISTRICTS

District	Block	Village	No. of farmers
(1)	(2)	(3)	(4)
Amravathi	Amravathy	Aasrigav poorna	10
		Nanori	10
		Javla Shapur	10
	Chandoor Bazar	New Akola	10
		Sukhali	10
		Nandorai	10
Yawatmal	Ner	Watfali	10
		Manikwada	10
		Dhanaj	10
	Yawatmal	Vagapur	10
		Jambavadi	10
		Laasina	10
Total			120

(iii) *Andhra Pradesh*

Andhra Pradesh is the third largest cotton growing state in India with 1.40 million hectares under cotton. In Andhra Pradesh, the districts, viz., Adilabad, Guntur and Warangal are the major cotton growing districts and each district covers an area of 15 per cent of the total cotton area in the state. The geographical and climatic features of Adilabad district are similar to Yawatmal district of Maharashtra. Yawatmal district was already covered under the study to represent Maharashtra and hence Adilabad district was not selected. Guntur and Warangal districts were selected from Andhra Pradesh and the sampling details are given in Table 3.

TABLE 3. VILLAGE WISE DISTRIBUTION OF FARMERS IN GUNTUR AND WARANGAL DISTRICTS

District (1)	Block (2)	Village (3)	No. of farmers (4)
Guntur	Dachapalli	Srinivasapuram	10
		Dachepalli Village	10
	Thadikonda	Nidumukkula	10
	Guntur rural	Tonnalagadda	10
Warangal	Bachennapet	Itkyapalli	10
		Nakkavarigudam	10
		Thamidapalla	10
		Chandrapuram	10
	Devaruppala	Devaruppala	10
		Sitaramapuram	10
		Kadavendi	10
		Nirmala	10
Total			120

(iv) *Tamil Nadu*

Tamil Nadu was purposively selected as it is one of the earlier adopters of Bt technology and has large area under Bt cotton. In Tamil Nadu, nearly 15 per cent of the area under cotton is in Virudhunagar district, while Salem (9.04 per cent), Madurai (8.38 per cent), Perambalur (7.59 per cent), Dharmapuri (6.84 per cent), Coimbatore (6.53 per cent) and Thoothukudi (6.39 per cent) are the other major cotton growing districts. Due to non-availability of adequate *Bt* cotton growers in the southern districts (Virudhunagar and Madurai) of Tamil Nadu, Salem and Perambalur districts were purposively selected where Bt cotton is widely cultivated. In this area

TABLE 4. VILLAGE WISE DISTRIBUTION OF FARMERS IN TAMIL NADU

District (1)	Block (2)	Village (3)	No. of farmers (4)
Salem	Kolathur	Ellaraimathikadu	10
		Kannamoochi	10
		Settiyur	10
	Mecheri	Aandikavundanur	10
		Virudhasampatti	10
		Mallikundham	10
Perambalur	Kunnam	Andhur	10
		Chitthali	10
		Anukur	10
	Veppanthattai	Nergunam	10
		Kudikadu	10
		Nergunam	10
Sub-total			120

Bt cotton cultivation is widespread and it was difficult to find the non-Bt cotton growers in the same village where *Bt* cotton was grown. Hence in order to get Bt and non-Bt samples in the same agro-climatic zone, six blocks were selected in total to meet the adequate number of non-Bt cotton sample farmers. The details of blocks and villages selected from the above two districts are given in Table 4.

(B) *Analytical Methods*

(i) *Impact of Bt Technology*

The impact of Bt technology on key variables like yield, pesticide use, profitability etc. were estimated through the following Analysis-of-Variance (AOV) model (Gujarati, 1988).

$$Y = \alpha + \beta C_{Bt} + u$$

where,

Y = Variable for which impact is estimated
C_{Bt} = 1 for adoption of Bt cotton
= 0 for non- adoption of Bt cotton.

This model estimates whether Bt adoption makes any significant difference in the yield, pesticide use, profitability, etc., assuming that all other variables are held constant. For example take the impact of Bt on yield. The intercept α gives mean yield of non-adopters and the slope β tells by how much the mean yield of adopters, differs from the mean yield of non-adopters. $\alpha+\beta$ gives the mean yield of the Bt adopter. The test of the null hypothesis that there is no difference between the yields of Bt adopters and non-adopters (H_0: $\beta=0$) can be made by running the regression in the usual manner and finding out whether the estimated $\hat{\beta}$ is statistically significant.

(ii) *Yield Advantage in Bt Cotton: Technology Effect or Input Effect?*

The yield advantage in Bt may be due to the Bt technology and/or due to additional input use for Bt cultivation. Sources of the yield difference between *Bt* and non-*Bt* cotton was estimated by decomposing the productivity change into technology effect and input effect following the methodology of Bisaliah (1977).

Figure 1 depicts the production technology of conventional hybrids and Bt hybrids. If the existing input use is X_0, the yield from conventional hybrid is Y_0 and yield from Bt hybrid is C. Y_0C is the yield gain due to technology. If the input use is increased to X_1, then the yield increases to Y_1 for Bt hybrids. Hence CY_1 is yield gain due to additional inputs. The production technology is represented as:

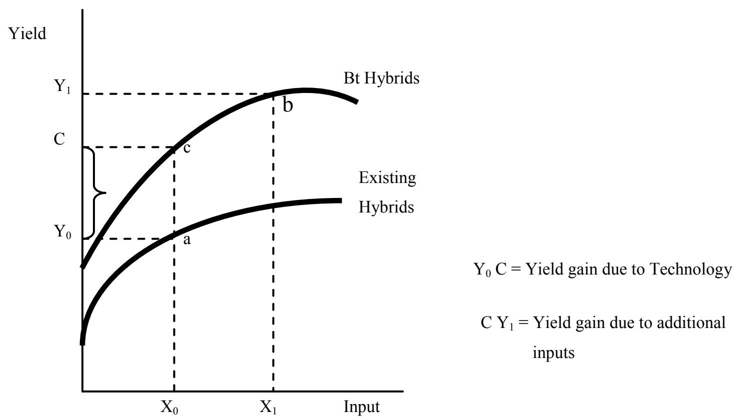


Figure 1. Decomposition of the Impact of Technology

The Production function for non-Bt cotton

$$\ln Y_0 = \ln \alpha_0 + \beta_{0i} \ln X_{0i} + u_0 \quad \text{…. (1)}$$

The Production function for Bt Cotton

$$\ln Y_1 = \ln \alpha_1 + \beta_{1i} \ln X_{1i} + u_1 \quad \text{....(2)}$$

Taking the difference of Eqn (1) and (2) and rearranging the terms, we get

$$\ln [Y_1/Y_0] = [\ln (\alpha_1/ \alpha_0) + (\beta_{1i} - \beta_{0i}) \ln X_{0i}] + \beta_{1i} \ln (X_{1i}/X_{0i})$$

Δ in yield = Δ in yield due to Bt technology + Δ in yield due to additional inputs

In the present study the following Cobb-Douglas production functions, for Bt and non-Bt cotton cultivation were fitted:

$$LnY_B = Lnb_0 + b_1 LnCHEM_B + b_2 SEED_B + b_3 LnFYM_B + b_4 LnN_B + b_5 LnP_B + b_6 LnK_B + b_7 LnLAB_B + b_8 LnIRRI_B + u_B \quad \text{…. (3)}$$

$$LnY_N = Lnb_9 + b_{10} LnCHEM_N + b_{11} SEED_N + b_{12} LnFYM_N + b_{13} LnN_N + b_{14} LnP_N + b_{15} LnK_N + b_{16} LnLAB_N + b_{17} LnIRRI_N + u_N \quad \text{…. (4)}$$

Where,

CHEM	= Cost of chemicals per acre
SEED	= Seed rate in grams per acre
FYM	= Manures in kg per acre
N	= Total nitrogen in kg per acre

P = Total phosphorus in kg per acre
K = Total Potash in kg per acre
LAB = Total labour in man-days per acre
IRRI = Dummy for irrigated environment (I=1 otherwise 0)
b_i = parameters to be estimated (i=1 to 8 for Bt and i=9 to 17 for Non-Bt)
u = random error
Subscript B = Bt cotton
Subscript N = Non-Bt cotton

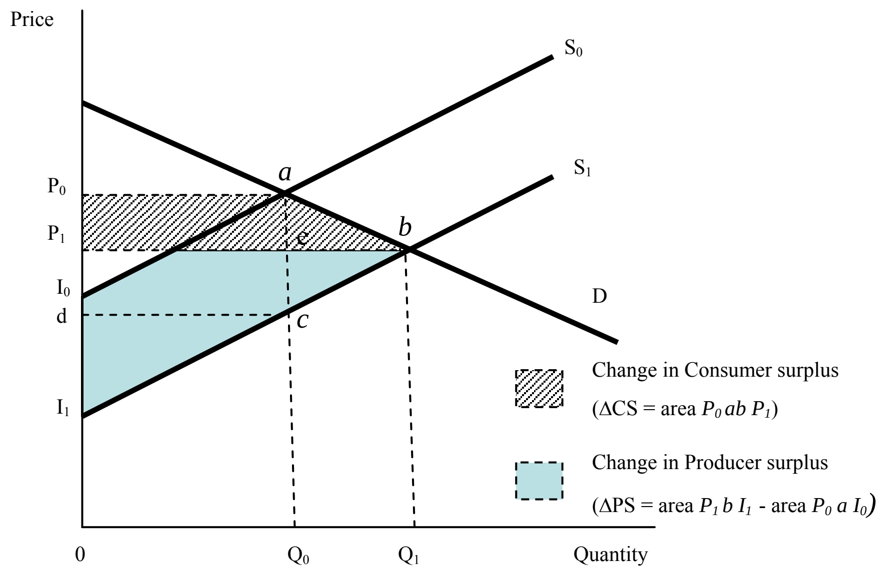
Taking differences between (3) and (4) and adding some terms and subtracting the same terms and by rearranging terms, the equation becomes;

$$LnY_B/Y_N = \{Ln(b_0/b_9)\} + \{(b_1-b_{10})LnCHEM_N + (b_2-b_{11})LnSEED_N + (b_3-b_{12})\ LnFYM_N + (b_4-b_{13})\ LnN_N (b_5-b_{14})\ LnP_N + (b_6-b_{15})LnK_N + (b_7-b_{16})\ LnLAB_N + (b_8-b_{17})\ LnIRRI_N\} + \{b_9)LnCHEM_B/CHEM_N) + b_{10}Ln(SEED_B/SEED_N) + b_{12}Ln(FYM_B/FYM_N) + b_{13}Ln(N_B/N_N) + b_{14}Ln(P_B/P_N) + b_{15}Ln(K_B/K_N) + b_{16}Ln(LAB_B/LAB_N) + b_{17}Ln(IRRI_B/IRRI_N)\} + \{u_B-u_N\} \quad ....(5)$$

LHS of the Equation 5 denotes the difference in per acre productivity of Bt and non-Bt cotton cultivation. The right handside (RHS) of the equation decomposes the difference in productivity into change due to technology and change due to input use. Equation 5 has three major terms within {}. The first term of RHS refers to the gap attributable to neutral technological change, the second term refers to the gap attributable to non-neutral technological change, and the third term refers to change due to input use.

(iii) *Economic Surplus and Distributional Impact of Bt Technology in India: The Economic Surplus Model*

Economic Surplus approach is widely used for estimating total benefits of a new technology and to evaluate its distributional impact. An economic approach to evaluating R&D begins with the basic, commodity market model of research benefits depicted in Figure 1. S0 represents the supply function before the technical change, and D0 represents the demand function. The initial price and quantity are P0 and Q0. Suppose research generates yield increasing or input saving technologies. These effects can be expressed as a per unit reduction in production costs, K, that are modeled as a parallel shift down in the supply function to S1. This research-induced supply shift leads to an increase in production and consumption to $Q_1(\Delta Q=Q_1-Q_0)$, and the market price falls to P_1 (by$\Delta P=P_0-P_1$). Consumers are better-off because the new technology enables them to consume more of the commodity at a lower price (Wood *et al.,* 2001).



Source: Alston *et al.,* (1988), p.209.

Figure 2. The Economic Surplus Model

Although they receive a lower price per unit, the producers who adopt the new technology are better-off, too, because their unit costs have fallen by an amount, K per unit that is more than the fall in price. The change in consumer surplus which is the measure of the consumer benefit is equal to area P0abP1. The change in producer surplus which is the measure of the producer gain is equal to area P_1 b I_1 - area P_0 a I_0 in Figure 2. The total benefit/the economic surplus is obtained as the sum of producer and consumer benefits. As an approximation, the cost-saving per unit multiplied by the initial quantity, K.Q0, is often used. Thus, the size of the market, as indexed by the initial quantity Q0, as well as the size of the research-induced savings in per unit cost of production. K, are critical factors in estimating the economic benefits from R&D. The economic surplus model was estimated through DREAM [*D*ynamic *R*esearch *E*valuation for *M*anagement] package, developed by International Food Policy Research Institute (IFPRI).

(iv) *Environmental Impact of Bt Technology*

One of the important characteristics of Bt technology is that it reduces pesticide use in cotton. There are different approaches to quantify the environmental impact of pesticide use. Marginal productivity estimates provide an indirect measure of the cost in terms of foregone agricultural output of reducing pesticide use to protect human health and environment (Campbell 1976). Higley and Wintersteen (1992) used a contingent valuation (CV) approach to assess the value to farmers of avoiding environmental risks caused by pesticides. They considered effects of pesticides on surface water ground water, aquatic organisms, birds, mammals, beneficial insects and humans. Mullen *et al.,* (1997) also used CV analysis to evaluate the impacts of pesticides. Kovach *et al.,* (1992) developed an Environmental Impact Quotient (EIQ) to measure the environmental impact of different pesticides. Environmental Impact Quotient (EIQ) value of individual pesticide refers to the average of its effect on farm worker, consumer and ecology. Later Oskam and Vijftigschild (1999) modified the EIQ field rating method to study the environmental impact of pesticides in agricultural use. In this study Environmental Impact Quotient (EIQ) values were adopted from Kovach *et al.,* (1992).

$$\begin{aligned} EIQ = \{ & C\,[(DT*5) + (DT*P)] \\ & + [(C*((S+P)/2)*SY) + (L)] \\ & + [(F*R) + (D*((S+P)/2)*3) + (Z*P*3) + (B*P*5)]\}/3 \end{aligned}$$

Where,

DT = dermal toxicity,
C = chronic toxicity,
SY = systemicity,
F = fish toxicity,
L = leaching potential,
R = surface loss potential,
D = bird toxicity,
S = soil half-life,
Z = bee toxicity,
B = beneficial arthropod toxicity,
P = plant surface half life.

To account for different formulations of the same active ingredient and different use patterns, a simple equation called EIQ Field Use Rating was developed.

EIQ Field Use Rating = EIQ x per cent of active ingredient x Rate

With this method, comparisons of environmental impact between pesticides and different pest management programmes can be made. Oskam and Vijftigchild (1999) developed an indicator to measure the risk of pesticides to the environment and other impact, RM using EIQ values as:

$$RM = \frac{\sum_{k=1}^{K} (\text{use of a.i.}_k \times EIQ_k) \text{ for crop } j}{\text{area of crop } j}$$

Where, RM = risk measure, a.i = active ingredient of pesticides, EIQ= Environmental Impact Quotient, k = 1,….n, insecticides and j = 1,…m crops.

IV

RESULTS AND DISCUSSION

The study analyses the impact of Bt technology on key variables in the production of Bt cotton like on yield, pesticide application, seed cost, labour and profitability across the states. Discussion across States facilitates comparison of key variables and help in understanding how the production environment in each state is different and accordingly how the impact of Bt cultivation varies across the states in terms of the key variables. Another way of presenting the results could be discussion of all the key variables for each state (state wise), however we follow the former.

Impact of Bt Technology on Yield

One of the important advantages of Bt technology on cotton is higher yield. This may be due to the prevention of yield loss due to pest attack. For example, the analyses of several years of Indian field trial data demonstrated that Bt technology can significantly reduce pesticide applications and increase effective yields under experimental conditions [Qaim and Zilberman 2003; Qaim 2003; ICAR 2002; Naik 2001]. According to Clive (2008) yield increased by 31 per cent as per conservative estimates for small farmers.

The impact of Bt technology on the yield of cotton in this study was estimated through the Analysis-of-Variance (AOV) model. The intercept of the model gives the mean yield of non-Bt. and the slope coefficient shows the difference in yield between Bt and non-Bt. The difference in mean yield was statistically significant in all states as shown in Table 5.

TABLE 5. IMPACT OF BT TECHNOLOGY ON YIELD

	Yield (kg/ha)	
States (1)	Intercept (Yield of Non Bt) (2)	Yield difference (3)
Gujarat	1685.59*** (14.446)	873.95*** (6.115)
Maharashtra	828.50*** (14.022)	338.08*** (4.672)
Andhra Pradesh	1902.67*** (24.456)	664.58*** (6.975)
Tamil Nadu	1739.50*** (25.69)	649.23*** (7.828)
All India	1539.06*** (25.997)	631.46*** (8.709)

*** Significant at 1 per cent level.

The estimated mean yield of non-Bt was 1903 kg per ha in Andhra Pradesh, 1740 in Tamil Nadu, 1686 in Gujarat and 829 in Maharashtra. The slope coefficient shows the difference in the yield of Bt and non-Bt. The mean difference in yield ranged from nearly 338 kg per ha in Maharashtra to 874 kg per ha in Gujarat. At all India level, mean difference in yield was 631 kg per ha which means the technology has increased the productivity of cotton by 631 kg per ha.

The mean yield of Bt was estimated as the sum of slope coefficient and intercept of the AOV model and the estimated mean yield of Bt and non-Bt is presented in Table 6. The yield of Bt cotton was the highest in Andhra Pradesh with 2567 kg per ha, followed by 2560 kg per ha in Gujarat, 2389 kg per ha in Tamil Nadu and 1167 kg per ha in Maharashtra. At all India average yield of Bt was 2171 kg per ha.

TABLE 6. YIELD OF BT AND NON-BT COTTON

States		N	Mean* (kg/ha)	T test	
				T	P
(1)	(2)	(3)	(4)	(5)	(6)
Gujarat	Bt	80	2559.54	6.115	0.00
	Non-Bt	40	1685.59		
Maharashtra	Bt	80	1166.58	4.672	0.00
	Non-Bt	40	828.50		
Andhra Pradesh	Bt	80	2567.26	6.975	0.00
	Non-Bt	40	1902.67		
Tamil Nadu	Bt	80	2388.74	7.828	0.00
	Non-Bt	40	1739.50		
All India	Bt	320	2170.53	8.709	0.00
	Non-Bt	160	1539.06		

* Differences in mean yields of Bt and non Bt are significant at one per cent level.

Impact of Bt technology on Pesticide Application

The Impact of Bt technology on pesticide application in cotton was estimated through the Analysis-of-Variance (AOV) model. The model shows whether Bt adoption makes any significant difference in the quantity of pesticide applied. The intercept of the model gives the mean expenditure on pesticides in non-Bt. The estimated mean expenditure on pesticides in non-Bt was Rs. 4707 per ha in Andhra Pradesh, 4262 in Gujarat, 2713 in Tamil Nadu and 2391 in Maharashtra. The slope coefficient of Bt shows the difference in the expenditure on pesticides in Bt and non-Bt. The expenditure on pesticides in Bt was less than non Bt and statistically significant in all states as shown in Table 7. The reduction in expenditure on pesticides ranged from Rs. 1718 per ha in Andhra Pradesh, Rs. 1713 per ha in Gujarat, Rs.1442 per ha in Tamil Nadu and Rs. 1057 per ha in Maharashtra.

The expenditure on pesticides for Bt was estimated as the sum of slope and intercept of the AOV model and the estimated expenditure on pesticides is presented in Table 8. The expenditure on pesticides in Bt cotton was the highest in Andhra Pradesh with Rs. 2989 per ha, followed by Rs. 2548 per ha in Gujarat, Rs. 1334 per ha in Maharashtra and Rs. 1271 per ha in Tamil Nadu. At all India average expenditure on pesticides in Bt was Rs. 2036 per ha. The Differences in average amount spent on pesticides between Bt and non Bt are significant at one per cent level in all the cases.

TABLE 7. IMPACT OF BT TECHNOLOGY ON EXPENDITURE ON PESTICIDE APPLICATION

States (1)	Expenditure on plant protection chemicals (Rs./ha)	
	Intercept (Expenditure – Non-Bt) (2)	Difference in expenditure (3)
Gujarat	4262.323*** (9.388)	-1713.82*** (-3.082)
Maharashtra	2391.014*** (15.128)	-1057.041*** (-5.461)
Andhra Pradesh	4707.203*** (24.824)	-1718.05*** (-7.398)
Tamil Nadu	2713.036*** (22.45)	-1441.73*** (-9.74)
All India	3518.394*** (23.847)	-1482.662*** (-8.205)

*** Significant at 1 per cent level.

TABLE 8. PESTICIDE EXPENDITURE ON BT AND NON-BT COTTON

States		N	Mean (Rs./ha)	T test	
				T	P
(1)	(2)	(3)	(4)	(5)	(6)
Gujarat	Bt	80	2548.49	-3.082	0.00
	Non-Bt	40	4262.33		
Maharashtra	Bt	80	1333.97	-5.461	0.00
	Non-Bt	40	2391.01		
Andhra Pradesh	Bt	80	2989.16	-7.398	0.00
	Non-Bt	40	4707.20		
Tamil Nadu	Bt	80	1271.31	-9.73961	0.00
	Non-Bt	40	2713.04		
All India	Bt	320	2035.73	-8.205	0.00
	Non-Bt	160	3518.39		

Earlier studies about the agronomic and economic impacts of Bt cotton cultivation demonstrated that the adopting farmers benefit from income increase through reduced pest control costs and higher effective yields (Morse *et al.,* (2004); Qaim and Zilberman 2003, Qaim and Traxler, 2005). The benefits will vary according to varying pest infestation levels in different years and locations. In China, for instance, infestation levels of lepidopteron pests are the highest in the northern and eastern parts of the country, and hence the benefits of Bt cotton were most pronounced there. This was reflected in much higher adoption rates, as compared to western China (Pray *et al.,* 2002). In South Africa, 90 per cent of the smallholder Bt cotton producers achieved significant reduction in pesticide use (Ismael *et al.,* 2001). In the Maharashtra State of India Narayanamoorthy and Kalamkar (2006) found that farmers cultivating Bt cotton had marginally higher expenditure of pesticides. They argued that the farmers spray the same quantity of pesticides as before because of the fear of bollworm attack. However Clive (2008) reported that insecticide application by small farmers in India decreased by 39 per cent on an average by conservative estimates.

Impact of Bt technology on Seed Cost

The GM cotton in India was commercialised in India by the multinational company Monsanto through co-operation with local seed companies. In GM cotton the Bt technology is embedded in seed and hence the cost of seed is higher in Bt cotton. The impact of Bt technology on seed cost in cotton was estimated through the Analysis-of-Variance (AOV) model. The model shows difference in the cost of seed purchased by Bt and non Bt farmers and the results were presented in Table 9.

TABLE 9. IMPACT OF BT TECHNOLOGY ON SEED COST

States	Seed cost (Rs./ha)	
	Intercept (Seed cost in Non-Bt)	Difference in seed cost
(1)	(2)	(3)
Gujarat	413.59***	1696.43***
	(6.715)	(22.49)
Maharashtra	1574.93***	889.05***
	(13.325)	(6.141)
Andhra Pradesh	1621.25***	1119.84***
	(15.515)	(8.750)
Tamil Nadu	1695.04***	618.03***
	(24.95)	(7.430)
Average	1630.40***1	776.63***
	(28.628)	(11.630)

Note: *** Significant at 1 per cent level; 1=excluding Gujarat.

The intercept of the model gives the mean expenditure on seed by the non- Bt farmers. The estimated mean expenditure on seed for non-Bt farmers was around Rs. 1600 per ha except in Gujarat, where the expenditure on seed was very low compared to other States. The slope coefficient shows the difference in the expenditure on seed cost in Bt and non-Bt. The expenditure on seed cost in Bt was more than non-Bt and statistically significant in all states. The increased expenditure on seed ranged from Rs. 618 per ha in Tamil Nadu to Rs. 1696 per ha in Gujarat. The seed costs of Bt and non-Bt cotton are compared in Table 10.

The average Bt seed cost in India was Rs. 2407 per ha. The seed cost was highest in Andhra Pradesh at Rs. 2741 per ha followed by Maharashtra, (Rs. 2464/ha) in Rs.2313 in Tamil Nadu and Rs. 2110 in Gujarat. The average non-Bt seed cost in India was Rs. 1630 per ha.

TABLE 10. SEED COST IN BT AND NON-BT COTTON

States	Bt_Non-Bt	N	Mean* (Rs./ha)	T test	
				T	P
(1)	(2)	(3)	(4)	(5)	(6)
Gujarat	Bt	80	2110.02	22.490	0.00
	Non-Bt	40	413.59		
Maharashtra	Bt	80	2463.98	6.141	0.00
	Non-Bt	40	1574.93		
Andhra Pradesh	Bt	80	2741.08	8.750	0.00
	Non-Bt	40	1621.25		
Tamil Nadu	Bt	80	2313.07	7.43	0.00
	Non-Bt	40	1695.04		
Average	Bt	320	2407.04	11.630	0.00
	Non-Bt	160	1630.41[1]		

*Mean difference significant at 1 per cent level; 1=excluding Gujarat.

Impact of Bt Technology on Cost of Cultivation

One of the areas of concern on Bt cultivation was that the adoption of Bt technology would result in increased cost of cultivation as a result of high seed cost and due to increased use of other inputs.

The estimates of cost of cultivation of non-Bt and the difference in cost between Bt and non-Bt cotton is given in Table. 11. The cost was higher in Bt cotton cultivation and the difference was statistically significant in all the States. The difference in cost was Rs. 5071 at all India level and among the States the difference in cost was the highest in Tamil Nadu and the lowest in Maharashtra.

TABLE 11. IMPACT OF BT TECHNOLOGY ON COST OF CULTIVATION

States	Cost of Cultivation (Rs./ha)	
	Intercept (Cost of Cultivation in Non-Bt)	Difference in Cost of Cultivation
(1)	(2)	(3)
Gujarat	22088.90***	5810.67***
	(13.492)	(2.898)
Maharashtra	13652.15***	1830.82***
	(23.62)	(2.587)
Andhra Pradesh	29855.04***	3251.93***
	(42.442)	(3.775)
Tamil Nadu	28046.82***	9388.65**
	(7.146)	(1.953)
All India	23410.73***	5070.52***
	(18.900)	(3.342)

*** and ** Significant at 1 and 5 per cent level, respectively.

A comparison of the cost of cultivation between Bt and non-Bt cotton is given in Table 12. At all India level the cost of non-Bt was Rs. 23,411 per ha and cost of cultivation of Bt was Rs. 28481. There was wide variation in the cost of cultivation of Bt ranging from Rs. 15483 per ha in Maharashtra to Rs. 37435 per ha in Tamil Nadu. In Maharashtra the cost of cultivation was comparatively low for both Bt and non-Bt cotton.

TABLE 12. COST OF CULTIVATION OF BT AND NON-BT COTTON

States		N	Mean (Rs./ha)	T test	
				T	P
(1)	(2)	(3)	(4)	(5)	(6)
Gujarat	Bt	80	27899.57	2.898	0.00
	Non-Bt	40	22088.90		
Maharashtra	Bt	80	15482.98	2.587	0.00
	Non-Bt	40	13652.15		
Andhra Pradesh	Bt	80	33106.98	3.775	0.00
	Non-Bt	40	29855.04		
Tamil Nadu	Bt	80	37435.47	1.953	0.03
	Non-Bt	40	28046.82		
All India	Bt	320	28481.25	3.342	0.00
	Non-Bt	160	23410.73		

Differences in cost of cultivation are significant at 1 per cent level except Tamil Nadu (5 per cent level).

Impact of Bt Technology on Profitability

The higher yield and reduced pesticide expenditure offset the higher cost of cultivation in Bt cotton resulting in higher profitability. The estimated mean profitability of non-Bt was Rs. 9516 per ha in Gujarat, Rs. 3502 per ha in Maharashtra, Rs. 7997 per ha in Andhra Pradesh and Rs. 4111 per ha in Tamil Nadu. The difference in mean profitability was statistically significant in all states as shown in Table 13.

TABLE 13. IMPACT OF BT TECHNOLOGY ON PROFITABILITY

States	Profitability (Rs./ha)	
	Intercept (Profitability in Non-Bt)	Difference in Profitability
(1)	(2)	(3)
Gujarat	9516.44***	27945.76***
	(3.308)	(7.931)
Maharashtra	3502.03***	5644.43***
	(2.789)	(3.671)
Andhra Pradesh	7997.32***	10276.33***
	(4.383)	(4.599)
Tamil Nadu	4110.73	16651.80***
	(0.864)	(2.858)
All India	6281.63***	15129.58***
	(3.851)	(7.573)

*** Significant at 1 per cent level.

The profitability for Bt was estimated as the sum of slope and intercept of the AOV model and presented in Table 14. The profitability in Bt cotton was the highest in Gujarat with Rs. 37462 per ha, followed by Rs. 20762 per ha in Tamil Nadu, Rs. 18274 per ha in Andhra Pradesh and Rs. 9146 per ha in Maharashtra.

TABLE 14. PROFITABILITY OF BT AND NON-BT COTTON

States		N	Mean (Rs./ha)	T test	
				T	P
(1)	(2)	(3)	(4)	(5)	(6)
Gujarat	Bt	80	37462.19	7.931	0.00
	Non-Bt	40	9516.44		
Maharashtra	Bt	80	9146.46	3.671	0.00
	Non-Bt	40	3502.03		
Andhra Pradesh	Bt	80	18273.65	4.599	0.00
	Non-Bt	40	7997.32		
Tamil Nadu	Bt	80	20762.53	2.858	0.00
	Non-Bt	40	4110.73		
All India	Bt	320	21411.21	7.573	0.00
	Non-Bt	160	6281.63		

Differences in profitability are significant at one per cent level.

The average profitability of Bt at all India level was Rs. 21411 per ha. Differences in profitability between Bt and non-Bt were significant at one per cent level in all states. The profitability was relatively very low in Maharashtra compared to other States.

Decomposition of Yield Increase into Technology Effect and Input Effect

A careful observation of these results justifies the necessity for decomposing the yield increase into technology effect and yield effect. It is evident that the higher profitability of Bt cotton was mainly due to higher yield and reduced expenditure on pesticides. But it is also important to note the high cost of cultivation of Bt cotton despite the reduced expenditure on pesticides which implies higher use of other inputs in Bt cotton cultivation. This indicates the higher yield in Bt cotton is due to Bt technology and higher input use. Hence the technology effect and input effect on yield increase was decomposed and presented in Table 15.

TABLE 15. DECOMPOSITION OF SOURCES CAUSING THE YIELD DIFFERENCE

(*per cent*)

Details	Gujarat	Maharashtra	Andhra Pradesh	Tamil Nadu	India
(1)	(2)	(3)	(4)	(5)	(6)
Due to technology	23.79	26.22	27.44	14.96	17.40
Due to input use	19.05	8.42	4.48	15.01	14.78
Estimated yield difference	42.83	34.64	31.91	29.98	32.18
Observed yield difference	51.85	40.81	34.93	37.32	36.95
Estimated yield difference as per cent of observed yield difference	82.60	84.88	91.35	80.33	87.09

The results show that the contribution of technology was higher than the contribution of higher input use to yield increase. At the all India level, the contribution of technology was 17 per cent of the higher yield and the contribution of higher input use was 15 per cent. The contribution of technology to yield increase varied from 27 per cent in Andhra Pradesh to 15 per cent in Tamil Nadu. In Gujarat, technology contributed for 24 per cent and higher input use contributed for 19 per cent of the higher yield. In Maharashtra the contribution by technology was 26 per cent while higher input use accounted for only 8 per cent of the higher yield. In Andhra Pradesh also contribution by the technology to yield increase was very high compared to the contribution by the higher input use. In Tamil Nadu the contribution by the technology and higher input use contributed 15 per cent each. The decomposition model accounted for about 80 to 90 per cent of the observed yield difference.

The Distributional Impact of Bt Technology: Economic Surplus Approach

The results in the foregoing sections indicate the gains from Bt technology. The nationwide impacts of higher production of cotton influence the macro supply and consequently the gains of producers and consumers. To understand this distributional impact was analysed through economic surplus approach and the results were presented in Table. 16.

TABLE 16. ESTIMATED ECONOMIC SURPLUS DUE TO BT COTTON

(*Rs.*)

	Supply Elasticity*		
	1.2	0.31	0.13
(1)	(2)	(3)	(4)
Producer surplus	147.29	254.53	292.36
	(40.00)	(72.07)	(86.02)
Consumer surplus	220.93	98.63	47.51
	(60.00)	(27.93)	(13.98)
Economic surplus	368.22	353.16	339.87
	(100.00)	(100.00)	(100.00)

Note: Supply elasticities were taken from Poonyth *et al.* (2004), Shepherd (2006) and Sumner (2003).

The producer surplus and consumer surplus were estimated under three supply elasticity scenarios of cotton. Under relatively inelastic supply assumption, 0.31 and 0.13, producers benefit more from the technology than the consumers and at elastic supply consumers benefit more than the producers.

Environmental Consequences

Under the Environment Protection Act (1986), the Ministry of Environment and Forests, has notified the Rules for the Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms/Genetically Engineered Organisms or Cells. Bt cotton being a transgenic crop requires environmental clearance under Rule 7-10 of the 1989 "Rules for Manufacture, Use, Import, Export and storage of hazardous microorganisms/Genetically Engineered Organisms or Cells" notified under the Environment (Protection) Act, 1986. The bio-safety and environmental issues related to this GM crop includes molecular characterisation of induced gene, biochemical characterization of the expressed protein, estimation of the level of the expressed proteins in cotton, proteins in cotton products, safety of the expressed proteins to non-target organisms, environmental fate of the Bt protein, and agronomic, compositional and food and feed safety evaluation of Bt cotton compared to non-Bt cotton seed. The different aspects of environmental consequences based on the survey data is presented below.

Incidence of Bollworm Attack in Bt and Non-Bt Cotton

Bollworm attack is the major cause of indiscriminate use of pesticides in cotton. Bt technology is specifically targeted against bollworm incidence in cotton. Farmers' experience with bollworm incidence in different states is given in Table 17.

In Tamil Nadu, there was no attack of American bollworm and spotted boll worm among the Bt farmers and 95 per cent of the farmers reported no attack of pink boll worm. In non-Bt there was moderate incidence of American bollworm in 68 per cent cases and severe incidence in 10 per cent cases. There was moderate incidence of pink bollworm and spotted bollworm in 38 per cent and 28 per cent of the farms respectively. In Maharashtra, there was no attack of American bollworm in 35 per cent of the Bt samples, mild attack in 51 per cent and moderate attack in 14 percent of the cases. In the case of pink bollworm 50 per cent reported no attack, 25 per cent reported mild attack, 20 per cent moderate and 5 per cent reported severe attack. In the case of spotted bollworm, 54 per cent of the farmers reported moderate attack. In Andhra Pradesh in Bt there was no attack of American boll worm in 88 per cent of the farms and there was mild attack in rest of the 11 per cent farms. In the case of pink worm there was no attack in 38 per cent of the farms, mild attack in 45 per cent and moderate attack in 18 per cent of the farms. There was no attack of spotted boll worm in 89 per cent of the respondents. In non-Bt 95 per cent of the cases reported moderate attack of American bollworm and pink boll worm. In Gujarat 84 per cent of the farmers reported no attack of American bollworm in Bt cotton, while 6 per cent reported mild attack and 10 per cent reported moderate attack. There was no incidence of pink bollworm in 96 per cent of the cases, but 35 per cent reported moderate attack of spotted boll worm. In non-Bt also in 70 per cent of the cases there was no attack of American boll worm while there was moderate attack of pink boll worm and spotted boll worm in 55 and 65 per cent of the cases respectively. In Tamil Nadu there was no attack of American boll worm in Bt crop while in non Bt there was no attack in 20 per cent cases. But in non-Bt there was moderate incidence in 68 per cent cases. Generally there was low incidence of boll worm compared to the past which indicates that farmers grow resistant non-Bt hybrids and in areas where boll worm incidence is generally low. There was no attack of pink worm in 95 per cent of cases in Bt and in 40 per cent of cases in non-Bt. In Tamil Nadu there was no attack of spotted boll worm in Bt while 28 per cent reported moderate attack in non-Bt.

TABLE 17. SEVERITY OF BOLLWORM ATTACK IN BT AND NON BT COTTON

		Gujarat		Maharashtra		Andra Pradesh		Tamil Nadu	
Pests (1)	Severity (2)	Bt (3)	Non-Bt (4)	Bt (5)	Non-Bt (6)	Bt (7)	Non-Bt (8)	Bt (9)	Non-Bt (10)
American BW	No attack	83.8	70.0	35.0	22.5	88.8	-	100.0	20.0
	Mild attack and no pp measures needed	6.3	2.5	51.3	45.0	11.3	5.0	-	2.5
	Moderate	10.0	20.0	13.8	20.0	-	95.0	-	67.5
	Severe	-	7.5	-	12.5	-	-	-	10.0
Pink BW	No attack	96.3	42.5	50.0	30.0	37.5	-	95.0	40.0
	Mild attack and no pp measures needed	1.3	2.5	25.0	37.5	45.0	5.0	1.3	2.5
	Moderate	2.5	55.0	20.0	20.0	17.5	95.0	3.8	37.5
	Severe	-	-	5.0	12.5	-	-	-	20.0
Spotted BW	No attack	57.5	32.5	22.5	20.0	88.8	-	100.0	67.5
	Mild attack and no pp measures needed	7.5	2.5	23.8	32.5	11.3	5.0	-	5.0
	Moderate	35.0	62.5	53.8	30.0		95.0	-	27.5
	Severe	-	2.5	-	17.5	-	-	-	-

Cultivation of Refuge Crops

Fields with *Bt* cotton are required to cultivate non-Bt cotton refuge to help control resistance. The refuge crop supply non-resistant insects to mate with possible resistant insects in Bt cotton to produce non-resistant insects. Thus refuge crop is meant to prevent the emergence of resistant pests which may require even higher dose of chemicals. Details of refuge cotton cultivation are given in Table 18.

TABLE 18. DETAILS ON REFUGE CROP CULTIVATION

(*Per cent*)

Details (1)	Tamil Nadu (2)	Maharashtra (3)	Andhra Pradesh (4)	Gujarat (5)
Awareness of refuge seed supplied	80	98	100	86
Use of refuge seeds	6	96	28	29
Awareness of susceptibility of refuge crop	100	53	36	43
Spraying of refuge crops	40	73	13	20

The Bt seed companies provide a small packet of refuge seeds along with Bt seeds to cultivate around the Bt fields. Most of the farmers in all the four States were aware of this refuge seeds. But only less than 30 per cent of the farmers used the refuge seeds for the purpose for which it was given. In Maharashtra nearly all the farmers used the refugee seeds as normal seeds and also sprayed the refuge crop to save from the boll worms, thus defeating the very purpose for which it was supplied. Awareness of the susceptibility of refuge crop was also very low except in Tamil Nadu. The reasons for not using the refuge seeds were analysed and presented in the Figure 3.

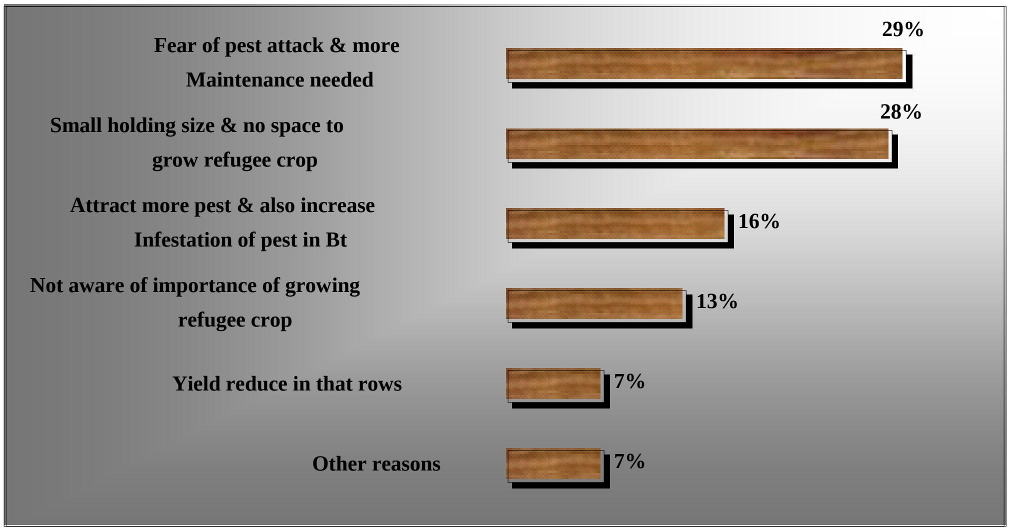


Figure 3. Reasons for Not Using Refugee Crop

The most important reason for not using refuge seeds was that farmers feared severe pest attack and more expenditure for pest control and reduced yield in refuge crop. In 28 per cent of the cases farmers found it difficult to comply with this measure because of small land holdings. The other important reasons were fear of pest attack in Bt cotton from refuge cotton, lack of awareness about the importance of growing refuge crop and fear of yield reduction.

Environment Impact Quotient (EIQ) of Cultivating Bt and Non-Bt Cotton

Environment Impact Quotient (EIQ) for Bt cotton was lower in all the states. The decrease in EIQ value was 15 per cent in Gujarat, 19 per cent in Andhra Pradesh, 50 per cent in Maharashtra and 68 per cent in Tamil Nadu. The variation in reduction in the EIQ could be due to the difference in pesticides used in different states and due to the difference in the incidence of sucking pests in different states. The pest control measure differs based on the level of sucking pest incidence.

TABLE 19. EIQ FIELD FOR BT AND NON-BT COTTON

(*rating/ha*)

State (1)	Bt cotton (2)	Non-Bt (3)	Difference (4)	Percent change over non-Bt (5)
Gujarat	43.23	50.64	-7.41	-14.63
Maharashtra	34.50	68.72	-34.22	-49.80
Andhra Pradesh	58.33	71.74	-13.41	-18.69
Tamil Nadu	26.58	82.31	-55.73	-67.71

Macro Trends: Before and After Bt Cotton

The macro trends in the area, production and yield along with a high level of adoption rate (86 per cent in 2010) brings out the level of acceptance of technology in the country. The area of cotton in the major producing states, which were nearly stagnant or declining for nearly a decade before the introduction of Bt in 2002-03, showed significant increase in most of the States. This is primarily due to the jump in productivity of cotton after the introduction of Bt cotton as evident from the Figure 4. This macro data confirms the results of this study on yield advantage. But there is decline in productivity in recent years. Decline in yield in one or two years could be due to climatic factors or other constraints. Nevertheless these data throws some light on the sustainability of the production potential of Bt in the long run and more rigorous studies are essential before making any conclusions.

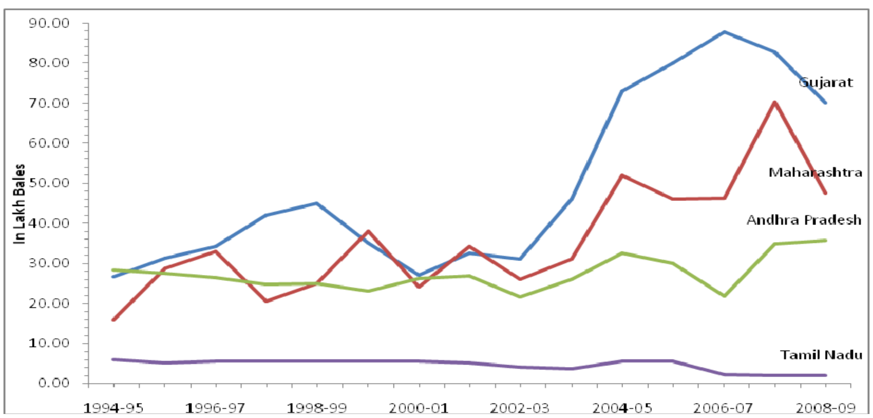


Figure 4. Productivity of Cotton in Major States

IV

CONCLUSION

Over the last ten years, modern agricultural biotechnology has been adopted rapidly at the global level, including several developing countries. In India this trend has been most apparent for Bt cotton in India in the last few years. But the introduction of Bt cotton in the country in 2002 led to an intense scientific debate and public controversy. The results of the study reveal that the farmers in the major cotton growing states in India benefitted significantly from adopting Bt technology through higher profitability mainly due to reduced pest control costs and higher yields, though there was considerable variation in key variables like yield, cost, pesticide use, etc., Cotton is one of the highest pesticide consuming crops which impact the environment through polluting land and water and poisoning humans, animals and insects. The environmental impact quotient was significantly lower for Bt cotton because of reduced pesticide consumption. The long term environmental impacts and bio-safety aspects of GM crops were not covered in this study.

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