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Farm-Level Economic Performance of Genetically Modified Cotton in Maharashtra, India

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A study of the commercial growing of *Bacillus thuringiensis* (Bt) cotton in India, compares the performance of over 9,000 Bt and non-Bt cotton farm plots in Maharashtra over the 2002 and 2003 seasons. Results show that since their commercial release in 2002, Bt cotton varieties have had a significant positive impact on average yields and on the economic performance of cotton growers. Regional variation showed that, in a very few areas, not all farmers had benefited from increased performance of Bt varieties.

India ranks third in global cotton production after the United States and China. With 9 million hectares grown in 2004/5, India accounted for approximately 20% of the world's total cotton area and 12% of global cotton production (Cotton Corporation of India). Cotton is a very important cash crop for Indian farmers. However, average cotton yields in India have been 300 kg/ha, compared with a world average of 580 kg/ha (Sen). One major limiting factor to cotton output is damage due to insect pests, especially bollworms. In March 2002, the Indian Government allowed commercial cultivation of genetically modified (GM) *Bacillus thuringiensis* (Bt) cotton. The Bt gene produces a protein that is toxic to bollworms. Some 29,000 hectares were planted with Bt cotton in 2002 in India, with

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over 12,000 hectares in the state of Maharashtra grown by over 17,000 farmers (Maharashtra State Department of Agriculture). This increased to some 86,000 hectares in 2003 (30,000 in Maharashtra) and to over 530,000 hectares in 2004 (205,000 in Maharashtra). Bt cotton plantings for 2005 have been estimated at over 1 million hectares in India (Monsanto), highlighting the continuing increase in adoption. The analyses presented here relate to cotton growers in Maharashtra.

G. hirsutum and *G. arboreum* are the two species of cotton grown in Maharashtra. Most of the cotton grown (73% of cotton area) is an intra-*hirsutum* hybrid, with the remainder being covered with improved (nonhybrid) *hirsutum* and *arboreum* cultivars. MECH-162 Bt, MECH-184 Bt, and MECH-12 Bt are three Mahyco–Monsanto Bt cotton hybrids grown in the subregions. Bunny, Tulsi, NHH-44, and JK-666 are popular non-Bt varieties. The analyses presented in this article compare the performance of plots with the former three Bt cotton hybrids (identified from seed company records) to those where non-Bt varieties were grown.

Given the importance of the cotton industry in India and the current global debate on the use of GM technology in developing countries (see, for example, Abdalla et al.; Food and Agricultural Organization; Friends of the Earth International; Nuffield Council on Bioethics), it is not surprising that there has been considerable and vigorous debate regarding the agronomic and economic performance of Bt cotton in India. Various reports have claimed both successes (e.g., AC Nielsen) and failures (e.g., Shiva and Jafri). The main debate has centered around whether Bt cotton consistently performs better than non-Bt varieties and whether adoption of Bt varieties results in an economic benefit to producers.

This paper presents a much needed and timely assessment of the performance of Bt cotton under typical farmer-managed conditions in India. The paper provides an analysis of data collected from a large sample of farmers growing conventional and Bt cotton under real commercial field conditions over two seasons, since Bt cotton has been licensed for commercial use in India (Food and Agriculture Organization). Unlike some previous Indian studies (e.g., Qaim and Zilberman), commercial field data are analyzed rather than trial plot data. As a result, this study meets the Food and Agriculture Organization's (FAO) call for more "market based studies" that will accurately reflect the agronomic and economic environments Bt cotton growers face. The analysis concentrates on addressing whether Indian farmers have experienced economic gains from growing Bt hybrids released by a company affiliated with Monsanto (Mahyco–Monsanto), compared with a complex of non-Bt hybrids and cultivars. The paper explores the performance of Bt varieties, including spatial differences.

Method

The analyses presented here relate to two random samples of Bt cotton growers in the state of Maharashtra over the 2002 and 2003 seasons. The data were based on a questionnaire survey carried out by trained and experienced agricultural extension workers of the Maharashtra Hybrid Seeds Company (Mahyco). Both the survey and the data were independently monitored by four teams from the Indian Genetic Engineering Approval Committee (GEAC), as well as scientists from the Central Institute for Cotton Research (CICR). The data were submitted to GEAC for evaluation of the performance of the first GM cotton in India. Maharashtra was selected because it is India's biggest cotton-growing state. In 2002, 17,658 farmers grew Bt cotton in the major cotton districts of Maharashtra. A questionnaire was prepared to capture all the relevant data to evaluate the performance of Bt cotton in the 2002 season. Some 2,709 farmers (15.34%) from 1,275 villages in 16 (out of 31 in Maharashtra) districts were randomly selected and interviewed in Khandesh, Marathwada, and Vidarbha—three cotton-growing sub-regions of the state.

The 2003 cotton season data were gathered using a shortened version of the 2002 questionnaire but covered four cotton-growing states (Maharashtra, Gujarat, Madhya Pradesh, and Karnataka). Farmers were randomly selected from villages known (from seed sales) to have Bt growers to ensure a reasonable sample size. Farmers were personally interviewed and data on cotton production (seed quantity/costs, number and cost of sprays, yields, cotton prices obtained etc.) were collected. Raw data from the two Mahyco surveys were analyzed with data from 787 Maharashtra farmers used from the 2003 dataset. In most cases, farmers grew Bt and conventional cotton varieties on the same farm, providing useful plot data for comparing the performance of both varieties for the same producer. This provides some "control" for a number of producer-related factors that might influence performance of the technology, such as entrepreneurial ability, age, experience, and expertise in growing the crop, and access to other inputs such as credit and irrigation. The data provide comparison across 7,751 plots in 2002 and 1,580 plots in 2003.

Production function analysis was used to further explore the relationship between cotton production inputs and yield per acre on each plot. A number of specifications were estimated—linear, quadratic, and log-linear. A Cobb–Douglas function provided the best fit. The estimation distinguishes between the Bt and non-Bt varieties using a dummy variable and dummy interaction terms. A complete model was estimated for the 2002 data and a more limited model for data pooled over two years (2002 and 2003) given the lack of information on some variables in the 2003 dataset. This pooling will help determine whether the results for 2002 reflect a "first year of production" impact and if there is pattern of change over time. Table 2 shows the specifications of the models used.

The models include all inputs for which there are data—land, sprays, soil type, and irrigation. Two important inputs—labor and fertilizers—have been omitted due to a lack of data. Therefore, the results carry the implicit assumption that labor inputs are the same on all plots which, of course, is a very simplistic assumption because labor requirements for insecticide sprays may be reduced through the adoption of Bt.[1] Omitting these variables may therefore cause some bias in the estimates, which is not always easy to determine.

The hypotheses are that cotton yields will increase with the quality of soil (dark brown being the most fertile), number of irrigations, and insecticide sprays. There is a possibility that response to irrigation and spraying may be quadratic in nature (i.e., diminishing returns) but when tested, this form of response was not significant. Land is more complicated. It is possible that small farms are intensively cultivated and therefore have higher yields. Larger farms, however, may benefit from economies of scale in cultivation.

The DUMBT term captures variation in yield for Bt varieties. *A priori*, this term might be expected to be positive, given previous studies based on trial data in India. Interaction terms between DUMBT and each of the inputs have been included in order to capture the possibility that the impact of each input on yield may vary between the Bt and non-Bt varieties.

Results

Table 1 shows a summary of the results comparing the costs and returns of growing Bt cotton and non-Bt cotton varieties for the two seasons. In both seasons, the non-Bt plots were larger than the Bt plots but yields (quintal/acre) of Bt cotton were significantly higher (by an average of 45% in the first season and 63% in the second season). This is despite both soil type and irrigation being much the same for the different types (at least in the 2002 season for which data on these are available). Expenditure on seed for Bt plots was over three times non-Bt plots, reflecting the relatively high cost of Bt cottonseed.

The use of sucking pest (such as aphids and jassids) sprays was slightly lower for the Bt plots in 2002, and slightly higher but not significantly different in 2003. It may be that in the first season some farmers did not fully understand the nature of the new technology and reduced spray use, believing that the Bt variety needed less. The use of bollworm sprays was much lower for Bt than for non-Bt plots. It should be noted that while Bt confers resistance to bollworm, some spraying may be beneficial as the Bt gene does not give 100% protection and resistance diminishes with plant age. By the second season, very little bollworm spray was applied to the Bt sample plots compared with more than three sprays for the non-bollworm plots (saving around 1,000 rupees per acre on average in that season).

There is a slight difference in the price per unit of cotton sold by producers for Bt (lower) compared to non-Bt in the first but not in the second season. It may be that in the first season there was some perceived uncertainty as to the acceptance of the Bt variety in some areas, which was reflected in a slightly lower price. The revenue from Bt cotton is significantly higher in both seasons due to the greater yields generally obtained on Bt plots. The final row of table 1 shows differences in gross margin (revenue less costs of seed and costs of sprays per acre)[2] across the two seasons. Gross margins are 50% or more higher for the Bt cotton varieties due to the higher yields of the Bt plots since any savings in bollworm pesticide costs are negated by the more costly Bt seed.

Analysis by district (not shown here) resulted in considerable and statistically significant spatial variation in yields for both Bt and non-Bt plots. Yields per acre ranged from 3.39 to 8.24 quintals in some districts for non-Bt plots in 2002 and 4.13 to 14.15 quintals for Bt plots. Similarly, in 2003, yields per acre ranged from 3.91 to 7.44 quintals in some districts for non-Bt plots and 5.54 to 13.14 quintals for Bt plots. All Bt plots in all districts had significantly higher average yields in 2003, but in 2002, 3 out of 16 districts showed little difference between the average yields from Bt and non-Bt plots.

Results of the production function estimation for 2002 (table 2) indicate that the Bt technology has a 33% positive effect on yield per acre (DUMBT), even after allowing for the influence of other inputs such as insecticide sprays, soil type, and irrigation. Yields rise for both the Bt and non-Bt varieties as the number of irrigations (LNIRRI) increase. However, there is an additional positive and highly significant impact on the Bt varieties (DUMIRRI). While this suggests that Bt varieties may do better under irrigation than non-Bt varieties, there also may be a

Table 1. Economic and agronomic performance of Bt cotton versus non-Bt cotton, Maharashtra, India

	Season 2002			Season 2003		
Variables	**Non-Bt**	**Bt**	**Sig.**	**non-Bt**	**Bt**	**Sig.**
Total cotton area planted (acres)	2.40 (1.6)	1.56 (1.7)	***	2.76 (3.2)	2.37 (3.4)	***
Soil type (3 categories)	2.22 (0.6)	2.23 (0.6)	ns	–	–	
No. irrigations	3.29 (1.7)	3.23 (1.6)	ns	–	–	
Cost of cotton seed (Rupees/acre)	460 (106)	1,527 (334)	***	471 (39)	1,491 (113)	***
No. sucking pest sprays	2.25 (0.8)	2.24 (1.1)	***	2.20 (0.9)	2.37 (1.1)	**
Cost of sucking pest sprays (Rupees/acre)	634 (319)	568 (322)	***	520 (309)	529 (289)	ns
No. bollworm pest sprays	3.84 (2.6)	1.44 (1.7)	***	3.11 (1.1)	0.71 (0.8)	***
Cost of bollworm pest sprays (Rupees/acre)	984 (576)	280 (295)	***	1,166 (658)	195 (278)	***
Total costs (seed plus insecticide) (Rupees/acre)	2,048 (841)	2,349 (638)	***	2,160 (823)	2,206 (432)	***
Cotton yield (quintals/acre)	6.09 (9.0)	8.83 (12.8)	***	5.59 (2.5)	9.10 (3.6)	***
Price of cotton (Rupees/quintal)	2,037 (225)	1,953 (415)	***	2,499 (91)	2,504 (91)	ns
Revenue from cotton yield (Rupees/acre)	12,577 (20,195)	18,049 (26,945)	***	14,001 (6,361)	22,807 (9,216)	***
Gross margin[a] (revenue − costs) (Rupees/acre)	10,524 (20,177)	15,700 (26,869)	***	11,849 (6,257)	20,600 (9,204)	***

Results are means and standard deviations in parentheses. Raw data failed Anderson–Darling test for normality, even with transformation, therefore data have been compared with the Kruskal–Wallis nonparametric test. ns = not significant at 5%; $^{**}p < 0.01$; $^{***}p < 0.001$.

[a]This is a partial gross margin since it does not include all variable costs such as fertilizer and labor for spraying, etc.

Table 2. Model results for 2002 season and for combined 2002/2003 seasons

		2002		2002 and 2003	
		Coefficient	*t*-Ratio	Coefficient	*t*-Ratio
	Intercept	0.51	11.85***	0.53	12.29***
Years (2002 = 0; 2003 = 1)	YEAR	–	–	0.003	0.07 ns
Logarithm no. irrigations	LNIRRI	0.05	4.89***	–	–
Logarithm sucking pest spray cost	LNSPSC	0.21	40.51***	0.21	44.086***
Logarithm cost bollworm sprays	LNBWSPC	−0.02	−3.16***	−0.007	−1.13 ns
Dark soil (=1)	DARKSOIL	0.12	6.57***		
Medium soil (=1)	MEDSOIL	0.05	2.96**		
Size of landholdings (acres)	LANDHOLD	−0.0006	−1.47 ns		
Vidarbha (1; others = 0)	REGION1	−0.19	−12.14***	−0.16	−11.30***
Marathwada (1; others = 0)	REGION2	−0.02	−1.17 ns	−0.02	−1.29 ns
Bt varieties (0 = non-Bt; 1 = Bt)	DUMBT	0.33	6.59***	0.48	10.35***
				–	–
Interaction terms (with DUMBT)	DUMBWSPC	0.01	1.82 ns	0.0008	0.12 ns
	DUMDSOIL	0.02	0.82 ns		
	DUMMSOIL	0.001	0.03 ns		
	DUMIRRI	0.10	5.24***	–	–
	DUMLANDH	−0.001	2.55**		
	DUMREG1	−0.19	−6.81***	−0.18	−7.31***
	DUMREG2	−0.22	−8.19***	−0.22	−9.16***
	DUMYEAR	–	–	0.21	5.48***
R^2		0.43		0.34	
Adjusted R^2		0.43		0.34	

ns = not significant at 5%; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.
The specification of the 2002 model is LNYIELD = f(LNLAND, LNIRRI, LNSOIL, LNSPSC, LNBWSPC, DUMBT, REGION1, REGION2, DUMBT ∗ all previous variables except LNSPSC). Inclusion of the latter interaction term resulted in a model with less explanatory power.
The specification of the pooled 2002/2003 data model is LNYIELD = f(YEAR, LNSPSC, LNBWSPC, DUMBT, REGION1, REGION2, DUMBT ∗ all previous variables [except LNSPSC], YEARLNSPSC, YEARLNBWSPC)
where
YIELD = yield (quintals per acre),
LAND = number of acres held by each farmer,
IRRI = number of irrigations (where rainfed cotton is held as 0),
MEDSOIL = medium soil = 1, otherwise = 0,
DARKSOIL = dark soil = 1, otherwise = 0, SPSC = cost of sucking pest sprays,
BWSPC = cost of bollworm sprays,
REGION1 = if region is Vidarbha, then 1; else = 0,
REGION2 = if region is Marathwada, then 1; else = 0,
DUMBT = dummy term denoting Bt varieties =1, if Bt; else 0.

seasonal effect and the response could have more to do with the variety carrying the Bt gene than the Bt characteristic itself. The coefficients of DARKSOIL and MEDSOIL show that, as expected, yields are highest on the heavier, darker soils followed by the medium and then light soils. Soil type has no significant effect on the Bt varieties, as shown by DUMDSOIL and DUMMSOIL.

Yield response to expenditure on insecticide sprays is more varied. Expenditures on sucking pest sprays generally increases cotton yields (as shown by LNSPSC) but yields appear to decline in response to expenditures on bollworm sprays (as shown by LNBWSPC), although not to the same extent for the Bt varieties (DUMBWSPC). However, including number of sprays rather than expenditures (not shown) show bollworm spray significantly increase non-Bt yields. The yield response is lower for Bt varieties, as might be expected. This difference in the analyses might suggest that non-Bt growers are spending too much on bollworm sprays and perhaps using too much insecticide each time they spray. However, it should be noted that interpretation is complicated because there is some substitution effect between nonbollworm and bollworm sprays and some insecticides used by farmers can control both bollworms and sucking pests. Moreover, in the later stages of growth, Bt yields can indeed benefit from spraying with bollworm insecticides.

Land is included as economies of scale variable. Results suggest that in general, large landholdings might have lower yields than small holdings but these results are not significant at the 5% level (only at the 10% level). However, they are significant for Bt varieties (DUMLANDH). It might be expected that yield per acre will be higher on smaller, more intensively farmed land.

There is evidence of spatial variation in yield. Region 1 (Vidarbha) has significantly lower yields than Region 2 (Marathwada) and Region 3 (Khandesh). This is true both for the Bt and non-Bt varieties. Interestingly, DUMREG1 and DUMREG2 show that the Bt cotton varieties have a greater effect on yield in Region 3 than in Regions 1 and 2. A more detailed statistical analysis of the regions indicates that there are a number of reasons for this pattern including intensity of input use. Diagnostics for the model indicate an adjusted R^2 of 0.43 indicating that approximately 43% of the variability in yields is explained by the model.

The above analysis considers data only for 2002, the first year of Bt cotton production. Therefore, it is not possible to consider if there is a time-varying pattern of yields in Maharashtra. More specifically, it is possible that the first year of production was particularly good or bad (in terms of weather, challenge by pests, etc.). The above model was re-estimated for data pooled over 2002 and 2003. However, there was no information available on soil type or number of irrigations for 2003. This could, of course, give rise to omitted variable bias. We tested the possible direction of such a bias by estimating the model for 2002 after excluding these variables and find that it does not change the direction of any of the coefficients.

Results for the pooled data (also in table 2) are similar to those for the 2002 cross-section, although the R^2 is lower at 34%. The variable DUMBT again shows (even more strongly with an estimated 48% increase in yield) the positive impact of the Bt variety on yields compared to conventional varieties, this time over both seasons. The story for sprays and region is the same as reported for 2002, except in the former the negative effect on yield of bollworm spray expenditure is not statistically significant. The yield of the Bt varieties is significantly higher in 2003 than in 2002 (DUMYEAR), with a greater relative effect of the Bt varieties in the second season. The effect is insignificant for the non-Bt varieties.

Further Analysis of Regional Differences

Our results indicated that Khandesh had the highest Bt and non-Bt yields among the three sampled regions. What might explain this pattern? Descriptive statistics of yields and input use in each of the three regions indicate that Khandesh falls between Vidarbha and Marathwada in terms of the average size of landholdings, cotton area planted per farm, and seed cost per acre (table 3). These factors do not readily explain the high yields in Khandesh. Farmers in this region, however, seem to use irrigation and sucking pest and bollworm sprays very intensively. Table 4 also confirms that the proportion of plots with dark soil is highest in Khandesh (19%) as opposed to 5.4% in Marathwada and 7% in Vidarbha.[3]

This pattern is repeated in the intensity of input use in Bt cotton production in the three regions. Table 5 indicates that Khandesh uses more irrigation and more sucking pest sprays on Bt plots than the other two regions. However, unlike for non-Bt cotton, farmers in Khandesh use less bollworm sprays on their Bt plots than other farmers. This might be because they are more discriminating and know that fewer bollworm sprays are required for Bt varieties or because they faced less bollworm infestation.

Discussion

The findings of this research can be put into the context of previous studies on Bt cotton. Many of these studies have shown potential gains to producers from growing Bt cotton in a number of developing countries (see James), including South Africa (Bennett et al.; Ismael, Bennett and Morse), Argentina (Qaim and De Janvry), Mexico (Traxler et al.), Indonesia (Manwan and Subagyo), China (Huang et al.; Pray et al.), and India (Naik; Qaim; Qaim and Zilberman).

Qaim and Zilberman report substantial benefits from Bt cotton adoption, with yield increases of 80% and more over conventional cotton varieties, from extensive field trial results in India. However, some have been critical of field trial data, since they may not be entirely representative of growing conditions in the wider farming community. Indeed, using commercial planting data, this analysis found lower (but still substantial) average yield increases of 45% and 63% for Bt plots across the seasons compared to non-Bt. After allowing for differences in pesticide use etc., production function model estimates were 33% and 48%, respectively, for the Bt varieties compared with non-Bt varieties.[4]

In assessing the benefits of the GM technology, it is important to recognize that there are likely to be a number of factors that could be contributing to the increased performance of Bt cotton. The first and most obvious is the Bt gene technology and the results presented here have shown a clear Bt effect. The second is the cotton variety used as the base for the Bt variety and its performance under local conditions. For example, it could be that the Bt cotton varieties use better (or worse) yielding hybrids than some of the conventional cotton grown. Thus, there may be both a Bt technology effect on performance (i.e., yield) and a hybrid

Table 3. Regional differences in input use (all varieties) in 2002

	Khandesh			Marathwada			Vidarbha		
	Mean	**SD**	**Number**	**Mean**	**SD**	**Number**	**Mean**	**SD**	**Number**
Value of cotton output (Rupees/acre)	18,240.60	8,186.78	1,879	16,277.70	40,733.80	2,541	12,680.50	26,041.40	3,019
Number of irrigations	3.27	1.29	1,942	2.09	1.64	2,575	3.02	1.62	2,756
Number of sucking pest sprays/acre	2.43	0.68	1,974	2.27	11.51	2,717	2.11	0.76	3,029
Number of bollworm sprays/acre	3.57	26.61	1,871	2.04	1.43	2,665	3.39	29.28	2,968
Farm size (acres)	14.81	14.39	2,009	12.96	15.52	2,721	18.75	14.91	3,063
Cotton area (acres)	8.07	8.66	2,009	4.25	5.37	2,721	9.52	7.91	3,063
Seed expenditure (Rupees/acre)	879.90	552.94	1,927	856.51	587.03	2,718	882.74	553.65	3,042

Table 4. Regional differences in soil quality in 2002

	All Cotton						Bt Cotton					
	Khandesh		Marathwada		Vidarbha		Khandesh		Marathwada		Vidarbha	
Soil Type	Number of Plots	%	Number of Plots	%	Number of Plots	%	Number of Plots	%	Number of Plots	%	Number of Plots	%
Dark soil	373	19.02	123	5.42	204	7.09	125	17.66	68	6.47	59	6.48
Medium soil	753	38.40	1,180	52.01	2,190	76.12	277	39.12	784	74.60	482	52.91
Light soil	835	42.58	966	42.57	483	16.79	306	43.22	199	18.93	370	40.61
Total	1,961		2,269		2,877		708		1,051		911	

Table 5. Regional differences in input use (Bt varieties) in 2002

	Khandesh			Marathwada			Vidarbha		
	Mean	SD	Number	Mean	SD	Number	Mean	SD	Number
Value of cotton output (Rupees/acre)	25,217.50	8,399.94	684	17,531.10	5,896.98	1,024	16,227.10	42,597.90	1,095
Number of irrigations	3.32	1.33	700	2.13	1.65	1,096	3.06	1.59	997
Number of sucking pest sprays/acre	2.41	0.68	711	2.34	17.67	1,150	2.04	0.77	1,092
Number of bollworm sprays/acre	1.24	16.19	610	1.08	0.98	1,119	1.95	23.88	1,042
Farm size (acres)	14.42	13.79	722	12.43	15.27	1,153	18.84	14.98	1,106
Cotton area (acres)	7.85	8.37	722	4.08	5.29	1,153	9.42	8.01	1,106
Seed expenditure (Rupees/acre)	1,589.65	112.43	718	1,419.57	500.56	1,150	1,598.26	106.21	1,104

effect. Third, it may be that more efficient farmers take up the new technology. These farmers may already be achieving higher yields than nonadopters before the technology. In addition, adopters may have planted the Bt seed on their better land and given it more attention than conventional varieties (given the relatively high cost of the Bt seed), although some analysis has been presented relating to land quality effects on yields. It has not been possible to clearly separate out all of these possible effects using the data available, and there is, therefore, a need for further data collection and research.

Conclusion

This study is one of the first of its kind in India based on "real" farms rather than the more artificial conditions that exist with trials. Findings show that since its commercial release in 2002, Bt cotton has had a significant positive impact on yields and on the economic performance of cotton growers in Maharashtra. This echoes the findings for a number of other developing and developed countries (see Baffes). However, it is important to note that there is spatial and temporal variation in this "benefit," and much can depend upon where production occurs and the season. Further data are required in future years to assess the ongoing performance of Bt cotton, and to separate out the influence of the Bt technology from other possible influences on performance. However, if the apparent advantages of GM cotton to farmers in India can be sustained, there could be a significant positive impact on farmers' livelihoods and on agricultural gross domestic product for India.

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Endnotes

[1]Other input labor, such as weeding, may also be different on Bt plots compared to non-Bt. For example, growers may expend more effort on weeding a more costly Bt seed.

[2]This is a partial gross margin since it does not include all variable costs, such as fertilizer and labor for spraying, harvesting, etc.

[3]Generally, Khandesh is more productive using irrigation resources and high inputs. Farmers in Marathwada generally use less inputs and are more dependent on rain for cotton cultivation. Vidharbha is largely rain fed but comes under assured rainfall areas. Farmers in this part generally use very low inputs and their spending on pesticides are the lowest in country and so is their yield.

[4]Variation in weather and pests between seasons may also contribute to differences between previous trial data and findings from commercial field data.

References

Abdalla, A., P. Berry, P. Connell, Q.T. Tran, and B. Buetre. *Agricultural Biotechnology: Potential Use in Developing Countries*. Canberra: Australian Bureau of Agricultural Resource Economics, 2003.

AC Nielsen. *Performance of Bollgard Cotton in 2003*. Mumbai, India: AC Nielsen ORG-MARG Pvt. Ltd. 2004.

Baffes, J. *Cotton: Market Setting, Trade Policies and Issues*. Washington DC: Development Prospects Group, The World Bank, 2004.

Bennett, R., T.J. Buthelezi, Y. Ismael, and S. Morse. "Bt Cotton, Pesticides Labour and Health: A Case Study of Smallholder Farmers in the Makhathini Flats, Republic of South Africa." *Outlook Agr.* 32(June 2003):123–8.

Cotton Corporation of India. Available at http://www.cotcorp.com/. Accessed June, 2005.

Food and Agriculture Organization of the United Nations (FAO). *The State of Food and Agriculture 2003–2004. Agricultural Biotechnology. Meeting the Needs of the Poor?* Rome: FAO, 2004.

Friends of the Earth International. *Genetically Modified Crops: A Decade of Failure (1994–2004).* Amsterdam: Friends of the Earth International, 2004.

Huang, J., S. Rozelle, C. Pray, and Q. Wang. "Plant Biotechnology in China." *Science* 295(January 2002):674–677.

Ismael, Y., R. Bennett, and S. Morse. "Farm-Level Economic Impact of Biotechnology: Smallholder Bt Cotton Farmers in South Africa." *Outlook Agr.* 31(June 2002):107–11.

James, C. "Global Review of Commercialised Transgenic Crops Featuring Bt Cotton." ISAA Brief No. 26. International Service for the Acquisition of Agri-Biotech Applications, Ithaca NY, 2002.

Maharashtra State Department of Agriculture. "Performance of Bt Cotton Cultivation in Maharashtra." Available at http://www.envfor.nic.in/divisions/csurv/btcotton/. Accessed June, 2005.

Manwan, I., and T. Subagyo. "Transgenic Cotton in Indonesia: Challenges and Opportunities." Paper presented at the regional workshop for the South East Asian Biotechnology Information Centers, Philippines, 30–31 July 2002.

Monsanto. "Bt Cotton in India: The Technology Wins as the Controversy Wanes." Available at http://www.monsanto.co.uk/news/. Accessed June, 2005.

Naik, G. *An Analysis of Socio-Economic Impact of Bt Technology on Indian Cotton Farmers*. Ahmedabad, India: Centre for Management in Agriculture, Indian Institute of Management, 2001.

Nuffield Council on Bioethics. "The Use of Genetically Modified Crops in Developing Countries." *A Follow-up Discussion Paper*. London: Nuffield Council on Bioethics, 2004.

Pray, C.E., J. Huang, R. Hu, and S. Rozelle. "Five Years of Bt Cotton in China—The Benefits Continue." *Plant J.* 31(August 2002):423–30.

Qaim, M. "Bt Cotton in India: Field Trial Results and Economic Projections." *World Dev.* 31(December 2003):2115–27.

Qaim, M., and A. de Janvry. "Genetically Modified Crops, Corporate Pricing Strategies, and Farmers' Adoption: The Case of Bt Cotton in Argentina." *Am. J. Agr. Econ.* 85(November 2003):814–28.

Qaim, M., and D. Zilberman. "Yield Effects of Genetically Modified Crops in Developing Countries." *Science* 299(February 2003):900–902.

Sen, A. "Cotton Scenario in India." Available at http://www.indiaonestop.com/cotton/. Accessed June 2005.

Shiva, V., and A. Jafri. *Failure of GMOs in India*. New Delhi, India: Research Foundation for Science, Technology and Ecology, 2003.

Traxler, G., S. Godoy-Avilla, J. Falck-Zepeda, and J.J. Espinoza-Arellano. "Transgenic Cotton in Mexico: Economic and Environmental Impacts." In *Economic and Environmental Impacts of First Generation Biotechnologies*, N. Kalaitzandonakes, ed., pp. 183–202. New York: Kluwer Academic Publishers, 2003.