On the 'Failure of Bt Cotton'
Analysing a Decade of Experience

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Given that the controversy over success and failure of Bt technology still exists, this paper discusses the available field studies that have addressed agro-economic questions of Bt cotton cultivation in India. Since a meta-analysis of studies can give only partial conclusions, owing to differences across study methodologies and coverage, this paper takes a different strategy, i e, looking not simply at differences between Bt farms and non-Bt farms, but at the experience of farmers before growing Bt and after switching to Bt. It also examines the more general problem of comparing field studies and suggests ways to use farmer behaviour as a proxy for settling different interpretations of agro-economic effects of the new technology. The study explains why there has been so much controversy given virtually universal adoption of Bt technology in cotton and concludes that in the battle of numbers around Bt cotton, those of the farmers have been curiously missing.

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1 The Puzzle

Intense controversy surrounds transgenic crops in much of the world. Results from India's first genetically engineered crop – Bt cotton – have figured prominently in global debates about agricultural biotechnology. Disputes about the effects of Bt cotton on production figured into controversy surrounding India's second transgenic crop: Bt brinjal (Solanum melongena aubergine, eggplant*)*. Politics and policy towards agricultural biotechnology in India for the future will be conditioned by the success or failure of Bt cotton. One prominent claim is that Bt cotton has caused "crop failures and mass suicides".[1] At the end of a decade of cultivation of this crop in India, an assessment of this claim seems timely.

Much of the controversy around biotechnology addresses ethical arguments, or concerns for multinational control, human health, or environmental effects.[2] Many of these questions resist empirical testing; some are matters of individual preferences. In all technological change, uncertainty is inevitable and different individuals will have different tolerance for uncertainty. Nevertheless, the claim that Bt cotton has caused crop failures and mass suicides belongs to a different category; it is an empirical claim about the actual state of affairs on the ground.

In assessing the empirics of Bt cotton, there are two nested but separable questions, one agronomic, one economic. The first Bt cotton hybrids in India contained a transgene from a common soil bacterium, Bacillus thuringiensis – abbreviated Bt. It conferred a trait: insect resistance. Has this particular transgene incorporated into cotton cultivars done what genetic engineering designed it to do? If so, does agronomic performance of the new crop induced by the transgene increase net income for the farmer sufficiently to cover higher costs of production, if production costs are higher? For example, in Bt crops, the claim of proponents is that seeds will cost more, but pesticide costs will decline. Is this true? What is the net effect on farmer incomes?

The charge that "Bt cotton has failed" originates from a loose coalition of non-governmental organisations (NGOs), often connected to transnational advocacy networks. Their narrative explicitly claims that (a) Bt technology lowers rather than raises on-farm yields and (b) Bt adoption drives farmers into debt because of high seed prices and agronomic failure, often resulting in catastrophe: sale of body parts and suicide (Herring 2006; Shiva 2006). Proponents of transgenic cotton argue that evidence from the field shows the same success in India that is apparent in China and other countries (James 2002).

This question is consequential. If critics are right, the large sums invested in biotechnology as a project of the developmental state promise only further misery for India's farmers. If proponents are right, technological change offers one of the few viable paths out of the classic poverty trap in agriculture – low yields, low income, low investment, resulting in low yields and on to another cycle. On sustainability grounds, Bt technology also claims to offer some relief from unsustainable pressures on rural ecosystems caused by the pesticide treadmill. How does one settle this dispute?

After this brief introduction, this paper discusses in Section 2 existing field studies addressing agro-economic questions of Bt cotton cultivation in India. Because a meta-analysis of studies can give only partial conclusions, owing to differences across study methodologies and coverage, we discuss in Section 3 data derived from a different strategy: looking not simply at differences between Bt farms and non-Bt farms, but at the experience of farmers before growing Bt and after switching to Bt. Section 4 examines the more general problem of comparing field studies and suggests ways to use farmer behaviour as a proxy for settling different interpretations of agro-economic effects of the new technology. In Section 5 we return to consider possible mechanisms for the origins of discrepancies in field reports of success and failure at the level of the farm. Section 6 looks at the aggregate picture: what can we say about Bt cotton in India's agricultural performance? In Section 7, the article returns to explain why there has been so much controversy given virtually universal adoption of Bt technology in cotton for reasons explored in previous sections. We conclude that in the battle of numbers around Bt cotton, those of farmers have been curiously missing.

2 Field Studies

Normal science takes a hypothesis, collects appropriate data and tests the proposition. Measuring inputs and yields in agriculture is not rocket science; the hypothesis of Bt cotton failure should be easy to test. But that has not proved to be the case.

Field studies are the starting point, but suffer from lack of comparability: what village, what farmers, what cultivars, what controls, what season? There is no space here to discuss all studies of Bt cotton, but some generalisations can be noted. Formal-sector studies (industry, government) were in the beginning most likely to find strongly positive agro-economic effects. These studies were reported in Parliament from officially sanctioned field trials of Bt cotton and offered confirmation of the standard narrative of Bt cotton advocates: harvested yields increased because of superior bollworm control; costs of bollworm control went down; therefore, net incomes went up. These results led to an official approval of Bt cotton for commercial release in March 2002. Academic studies were more nuanced but largely confirmed this story; in general, formal-institutional analyses reinforced the position of the Department of Biotechnology.[3] The studies conducted by NGOs (Gene Campaign, Deccan Development Society) contradicted these conclusions and supported the Bt failure narrative: lower yields, higher debt and sometimes serious externalities.[4] These studies have become increasingly isolated over time, though they persist in the media and in global advocacy networks. Recent studies have converged around rejection of the failure narrative and affirmation of the success story. We do not know of any peer-reviewed study that confirms failure of the Bt technology in cotton, but doubts remain prominent in civil society.

The standard practice in the face of conflicting results is to conduct a meta-analysis of all studies. Not all studies are comparable as some measure only a subset of the variables that others measure. Nevertheless, one meta-analysis of studies relevant to the reported connection between farmer suicides and Bt cotton did attempt a systematic comparison (Gruère et al 2008). Sponsored by International Food Policy Research Institute, this analysis covered both peer-reviewed and non-peer-reviewed published field studies. It found that across 22 field studies available for comparison, covering 12,931 farming plots, net returns from Bt cotton farming increased by 53.5% as a weighted average in comparison with non-Bt fields. The reasons for this increase in income were as predicted: a weighted average of 34.4% decrease in pesticide use (on 11,136 plots), leading to a 45.8% decrease in pesticide cost and a 39.1% increase in yields. As critics argued, total costs of cultivation in the studies increased – by an average 15.0% – but increased costs were more than compensated by better yields, resulting in higher net incomes for farmers.[5]

A meta-analysis is decisive only if there is broad agreement on the components of the field of studies being surveyed. Some studies by local groups are not generally available, nor are sampling techniques always specified, nor yield measurement. Studies finding crop failure were criticised in the scientific community for lacking rigour and transparency. Opponents of Bt cotton rejected studies reporting positive agronomic effects as biased by corporate or state sponsorship. Peer review itself as a standard for establishing integrity of findings was rejected by some opponents of Bt cotton. There were regional differences as well. Reports of failure, including the most detailed (Qayum and Sakkhari 2005), often came from Andhra Pradesh. No studies known to us reported failure in Gujarat, where the making of transgenic cotton hybrids became a rural cottage industry – albeit an illegal one (Gupta and Chandak 2005; Herring 2007b).

Problems of comparability across studies led us to employ two alternative methods. First, to answer critiques that cross-sectional studies fail to control for critical variables – soil quality, farmer skill, education and connections, class, irrigation, etc, – we present data from a before-and-after field study in areas where reports of failure have been prominent: Andhra Pradesh. The before-and-after study follows the same farmers in the same fields; the only change in cotton farming is the adoption of Bt hybrids by those farmers. These findings confirm that the cross-sectional studies in the same areas – Bt vs non-Bt farms – are not biased by hard-to-measure effects of farm management, farmer characteristics or agronomic potential of particular farms. Second, in Section 4, we look to Andhra Pradesh as a potential regional outlier given the prominence of suicide claims and failure in that state through a field investigation of sources of discrepancies in reported data.

3 A New Analytical Strategy: Before and After Bt Compared to With and Without Bt

This section analyses panel studies from Andhra Pradesh at the midpoint of the decade of Bt cotton experience in India. Data allow us to track the farming situations before and after the adoption of Bt of 186 farmers in 2004-05 and 2006-07, respectively. In the second round of study, all farmers had shifted to Bt hybrids, enabling analysis of what happened to outcomes on the same farms after adoption. Before-and-after comparisons found statistically significant yield and net income increases from Bt adoption, similar to the superior performance of Bt farms compared to non-Bt farms in the same sample a year earlier, in 2004-05. Table 1 illustrates the conventional strategy of comparing Bt to non-Bt farmers' results by taking a sample containing 437 Bt farmers and 186 non-Bt growers in 2004-05. It illustrates the story common in the meta-analysis: Bt cotton farms reported higher seed costs, lower insecticide costs, higher yields, lower cost per quintal of cotton produced and higher net income. As the growers of cotton containing the transgene achieved better results than farmers using conventional cotton hybrids in 2004-05, the demand for the seeds was so high that Bt seeds were often sold with police protection in the state.[6] This rush to Bt is illustrated in the sample itself: by 2006-07, all farmers had switched to Bt, allowing the before-and-after comparison as a natural experiment.

Another often-mentioned issue relating to the new cotton is that the small farmers lose out in their effort to harness the technology (Glover 2010). Several studies show that this is not true, and in fact, they gain more relative to their earlier position, though the better-off farmers gain more in an absolute sense (e g, Rao and Dev 2010; Subramanian and Qaim 2009, 2010). We present here some results from the study of Rao and Dev (2010: Chapter 6) that clearly demonstrate that size, social category,

Table 1: Costs and Returns in Bt Cotton vis-à-vis Non-Bt (NBt) Cotton in 2004-05 (per acre in Rs)

Item	Bt	NBt	Percentage Change
Hired labour	1,780	1,476	20
Attached labour	218	127	72
Bullock labour	859	855	0.47
Machine labour	708	587	21**
Seed	1,402	598	134**
Manure	515	406	27
Fertilisers	1,579	1,603	-2
Insecticides	2,673	3,267	-18**
Irrigation (irrigation and electrical) (charges)	94	84	12
Miscellaneous	94	84	12
Total cost	9,922	9,087	9
Physical yield in quintals	9.49	7.21	32**
Cost of production per quintal	1,046	1,260	-17*
Gross income	16,612	12,338	35**
Net income	6,690	3,251	106**

While net income is excess of gross income over all costs, farm business income is the excess of gross income over variable costs.
In Tables 1 and 2, *, **, *** indicate statistical significance at 1%, 5% and 10% levels.
Source: Rao and Dev (2010: Chapter 5).

Table 2: Costs and Returns Before-and-After Adoption of Bt Cotton (per acre in Rs)

Item	After Adoption (Bt)	Before Adoption (Non-Bt)	% Change over non-Bt*
Hired labour	1,726	1,476	4
Attached labour	67	127	-53
Bullock labour	906	855	-6*
Machine labour	886	587	34*
Seed	897	598	34*
Manure	380	406	-17**
Fertilisers	1,723	1,603	-4***
Insecticides	1,599	3,267	-56*
Irrigation (irrigation and electrical) (charges)	55	54	-9
Miscellaneous (repairs and transport)	88	84	-7*
Total cost	8,327	9,057	-18*
Physical yield in quintals	10.27	7.21	42*
Cost of production per quintal	811	1,256	-55*
Gross income	19,722	12,338	42
Net income	11,395	3,281	209*

* The percentage changes are worked out using the monetary values in constant prices, which are not presented in the table.
The non-Bt farmers in 2004-05 represent the before adoption scenario. The same farmers adopted in 2006-07 and they are taken to represent after adoption scenario.
Source: Rao and Dev (2010: Chapter 5).

Figure 1: Percentage Change in Yield and Net Income after Adoption of Bt in 2006-07 for Different Size and Social Categories of Farmers

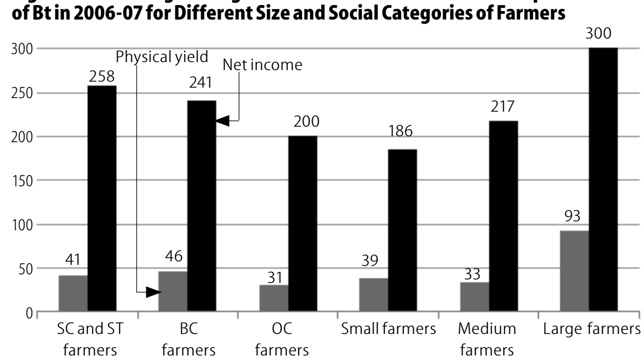


Figure 2: Percentage Change in Yield and Net Income after Adoption in 2006-07: Different Agro-climatic Zones

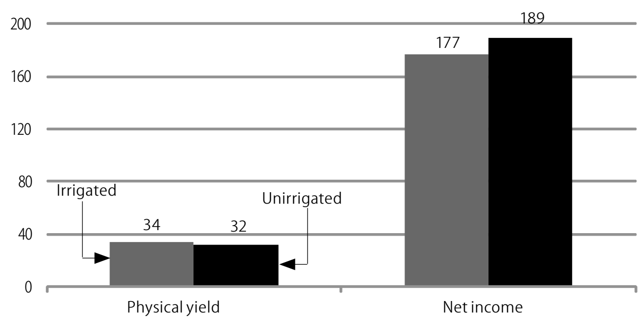
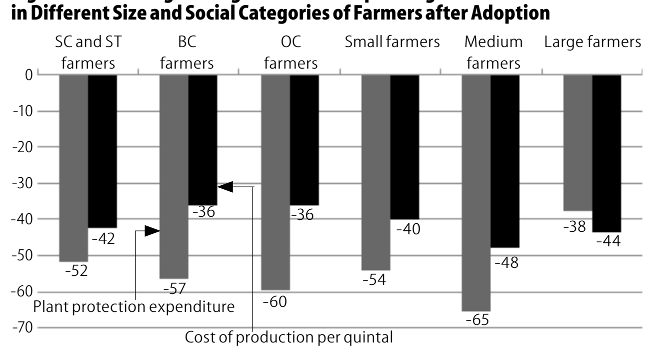


Figure 3: Percentage Change in Pesticide Spending and Cost of Production in Different Size and Social Categories of Farmers after Adoption



irrigation or lack of it and agro-climatic zones did not matter in getting superior results from the technology (Figures 1 to 3, p 47). Figure 1 demonstrates that across social categories and farm size, Bt adoption resulted in increases in physical yield and net income. The social categories are scheduled caste/scheduled tribe (SC/ST), backward caste (BC), and other caste (OC). Farmers are divided into categories of small, medium and large, as is conventional, based on the size of landholding. Figure 2 shows the effects of irrigation: farmers from both irrigated and unirrigated cropping conditions gained by the same criteria. Results shown in Figure 3 bear on the question of environmental effects and sustainability as well: farmers of all size and social categories reduced plant protection expenditure (on pesticides) and produced each quintal of cotton at a lower cost.

4 Exploring Mechanisms: Farmer Behaviour as Check

Studies are limited by time and space and are often not comparable. What gets studied depends on the priorities of funding and interests of researchers. Moreover, data in field studies are social products, dependent on the relations of production between data producers and subjects in an artificial setting. An alternative way to measure the effect of any technology is to analyse the trajectory of large numbers of individuals using it. Consider the mobile telephone: it may well be a health risk or offensive in some social settings, but it is hard to dispute the utility of the technology to users. Can we look into farmer behaviour, a proxy for variables contested in field studies?

The virtually universal adoption of transgenic cotton in India alone would lead one to question the representativeness of studies reporting failure. Bt cotton technology has been available legally since 2002, and illegally since 1999; if it is failing, would we not see massive dis-adoption – not of specific cultivars, but of Bt technology? One study did document dis-adoption after crop failure and loss of income; it came from Warangal district in Andhra Pradesh (Qayum and Sakkhari 2005). This outcome is especially puzzling because the all-India data showed adoption rates to have been higher in Andhra Pradesh than in other states in the same period (Herring 2008b). Warangal figured prominently in early concern with farmer suicides and in the book *Seeds of Suicide* (Shiva et al 2000). One entry into the puzzle could be to look at the district most often mentioned in failure reports to see whether conditions were different from the rest of India: could there be a district effect? Specifically, are there mechanisms in Warangal that might explain divergent interpretations of the national trend?

One local refutation of the notion that farmers adopt Bt technology because of higher incomes with less pesticide contamination is that there is no choice. By 2010, virtually everyone agreed that non-Bt cotton seeds were disappearing from the market. The question is why. Devinder Sharma, a prominent commentator on Bt cotton, said at a public forum at the India International Centre in New Delhi on 4 December 2009, that there were no non-Bt cotton seeds available because the government prevented their sale through the Essential Commodities Act (personal communication). International narratives about India have stressed the power of Monsanto in preventing the production of non-Bt cotton seeds. Could these claims explain rapid adoption even in areas of widely reported distress, including suicides?

In Andhra Pradesh, it is clear that the dynamic worked in the opposite direction: the demand for conventional seeds began to decline as Bt hybrids became more available. As early as 2004-05, there were instances of police protection for sales of Bt seeds in the state. Interviews with local representatives of seed companies in Andhra Pradesh in 2006 revealed that the growth in demand for Bt cotton seeds had been exceptional and unanticipated.[7] Nuziveedhu Seeds had in 2006 put out its first transgenic cotton, on licence from Mahyco-Monsanto Biotech (MMB) and found demand far exceeding supply. They produced 10,000 seed packets; demand proved to be around 40,000. Representatives from seed firms reported large stockpiles of unsold non-Bt seeds, for which there was no demand. Farmers throughout the state were switching to Bt hybrids; the local seed industry had to gear up quickly to expand Bt hybrids.

The then director of the Andhra Pradesh Seed Certification Agency in Hyderabad estimated in 2006 that Bt hybrids constituted 85-90% of the cotton area in the state. Yet it remained possible that industry and government estimates of a statewide phenomenon concealed variance at the district level. Scientists at the agricultural research station of Acharya N G Ranga Agricultural University (ANGRAU) in Warangal district, the most senior of whom was cited as an authority by Shiva et al in *Seeds of Suicide* (2000), estimated that 80-90% of the cotton in the district was Bt cotton in 2006. Officers in the Department of Agriculture in Warangal town estimated that 95% of the cotton area in the district was transgenic. Local seed merchants on Station Road estimated a somewhat higher figure – 98%. Some had ceased to stock non-Bt cotton hybrids because there was no demand for them; their perception of the local market matched that of state-level seed companies. These numbers are consonant with the conclusion of anthropologist Glenn Stone's (2007) detailed empirical work in Warangal district: farmers were adopting Bt cotton with such alacrity that it was "more than innovation adoption, more than a tipping point: it was a craze".[8] The gap between supply and demand allowed some hucksters to market counterfeit Bt seeds (Herring and Kandlikar 2009).

Unstructured interviews with farmers in Warangal district confirmed of the dominant finding of formal field studies in the rest of India: farmers grow Bt cotton for higher incomes through better pest management at lower cost. The extent of benefit varies with the level of pest infestation; in heavy pest years, Bt technology saves cotton crops; in years of moderate or low infestations, the enhanced cost of the Bt seed is subjectively discounted as insurance. This insurance cost is more expensive in officially approved Bt hybrids than in the cheaper Bt stealth seeds, assuming they contain the Bt transgene. The highest yield encountered in unsystematic sampling in Warangal district in 2006 was of an unlabelled "Gujarat Bt", though there were illicit Bt seeds from Kurnool district within the district as well.

Agro-chemical dealers in their shops, along with farmers coming and going, confirmed these results. Their livelihood depends on monitoring farmer behaviour; they cannot continually deceive farmers with exaggerated or false claims. Some have been physically punished for trying. Local insecticide sales were estimated to be down by 60%. Some dealers had lost half their cotton pesticide business; a few reportedly closed shop. Spraying for sucking insects in cotton, and sometimes overly-cautious excessive spraying for bollworms, continued, but the reduction of pesticide use was substantial – around half in the estimates of local farmers and agro-chemical dealers. To people who sell and grow Bt cotton, the notion that "Bt cotton has failed" was incomprehensible.

Why then are there reports of failure in Warangal? History and policy provide some help in explanation. Adulterated cotton seeds from the firm Excel had failed farmers in 2000, before Bt cotton was on the market; the firm was forced to pay compensation. When some farmers in the district demanded compensation in 2004 for Bt cotton failure, they were relying on a proven model of gaining resources. The administration in this district was especially sensitive to rural protest because of a history of Maoist agrarian insurrectionist activity. Mahyco-Monsanto agreed to pay Rs 3.27 crore compensation to farmers despite denying culpability; their calculation was that it was an acceptable price to pay for staying in the cotton market in Andhra Pradesh, where they had Rs 15 crore of business (Herring 2008b). Politics and policy in the state in the form of ex gratia payments for farmer suicides produced perverse incentives, as parodied in the popular film *Peepli Live* and recognised by the state government as early as 1998. Despite incentives to claim failure of Bt seeds, behaviour in the fields produced evidence of general satisfaction with the technology. When three cultivars of Bt cotton produced by Mahyco-Monsanto were banned in Andhra Pradesh on grounds of agronomic failure, at least one of these hybrids – MECH 12 – was sufficiently popular with farmers that some travelled across state lines to procure it, from Nanded and other locations in Maharashtra.

The all-India story of adoption of Bt technology parallels the Warangal story. Despite court stays and state government bans, Bt cotton hybrids are now essentially universal. In his announcement of the moratorium on Bt brinjal in 2010, the then minister of environment Jairam Ramesh stated that more than 90% of cotton farmers in India grow Bt cotton. Without adopting the most demeaning cultural urban bias, it is difficult to think that farmers would adopt and spread a technology that is literally killing them.

5 Why Do Studies Find Failure?

Discussions of field studies have often conflated performance of specific cultivars with performance of Bt technology. India has heterogeneous agro-climatic and socio-economic conditions. As a consequence, different cultivars are used in different areas in different years; farmers frequently switch hybrids. Because of agronomic differences, cultivars that work well in one region, district, farm, or even field, may fare less well in the next. Each hybrid of cotton contains somewhat different germ plasm. Bt technology only confers one trait; some hybrids with this trait do better than others. The only thing that Bt hybrids have in common is this one trait: insect resistance conferred by a transgene. There are over 800 legal hybrids with this specific trait, generated by Bt gene insertion. Not even the mechanism for obtaining the trait is exactly the same in all cultivars: Nath Seeds, for example, used a Bt construct from the Chinese public sector in its hybrids; J K Agri of Hyderabad used an indigenously developed Bt gene construct; some MMB hybrids (BGI) use the conventional cry1Ac gene (now present in brinjal varieties and hybrids under consideration for deregulation), whereas others use a stacked-gene technology (BGII). The new public sector Bt cotton is not a hybrid, but an open-pollinated variety, designed to facilitate seed-saving for farmers who prefer to do so.[9] There are still many illegal Bt cotton hybrids as well – deshi Bt. One would expect variance in performance of Bt cottons ex ante.

For precise measurement of the independent contribution of Bt technology – the additional trait – to yields, we would ideally compare isogenic cultivars, one with and one without the transgene, to isolate the effect of the technology. None of the claims of Bt failure compared two isogenic cultivars, one with and one without the Bt gene, to assure control of varietal characteristics.[10] An analysis by Naik et al (2005) found that cultivar differences were a major source of variation in results in yield comparisons. By analogy, we would not ask the question: "has word-processing software failed?" Instead, we would ask what software on what machine doing what tasks? And we would compare the genre of technology to alternatives, like paper and pencil or typewriters, before declaring failure of word-processing technology.

Some reports of failure attributed all problems in cotton cultivation to Bt. Characteristics of specific hybrids such as staple length, boll size, seed density and sensitivity to drought or wilt have been used to demonstrate failure. However, the cry genes inserted to produce the Bt insecticidal protein have no biological connection to these phenotypic variations.[11] These differences across cultivars are reflections of the different germ plasm in different hybrids. If cotton hybrids did not differ, there would not be hundreds of them grown in India. Unless researchers control for cultivars, variation between the Bt crop and the "check" crop may simply reflect phenotypic differences resulting from different germ plasm in the plants. The illegal Navbharat 151 contained superior germ plasm, explaining its persistence as a base for deshi, though illegal, Bt variants. Farmers experiment widely with different cultivars; even in the same area, some cottons work better in some fields, for some farmers, than others (Roy 2006). There are many unmeasured variables in producing yield results, often in complex interactions, including soil ecology, microclimate, water timing, soil chemistry, pest incidence and availability of nutrients. One of the most criticised of the early official Bt hybrids, MMB MECH 184, wilts when subjected to early moisture stress. This hybrid is probably the source of NGO reports that Bt causes leaf wilt. Yet some farmers with good water control have found MECH 184 their best producer (Roy et al 2007).

Some reports of failure of the technology stem from a different problem that is harder to correct: fraudulent practice in an unregulated seed market. Even with proper controls for germplasm, field studies may err because some seed packets labelled "Bt" do not contain Bt cottonseeds. "Duplicates" are frauds on farmers; missing the transgene, they do not produce the cry protein[s] that provides insect protection. There have been cloth-bag, farmer-generated and F2 Bt seeds that do produce the cry insecticidal protein but at uncertain levels; their germ plasm may be very good or not so good. Without a seed certification process that works, the farmer does not know. The analogy would be downloading software of unknown provenance from the web to save money: it may or may not be what it represents itself to be. Shortages of Bt seeds in the early period because of regulatory restrictions and expanding demand led to shortages. As a result, seed stock of ambiguous heritage entered the villages and was sold as Bt; there was widespread fraud. In Warangal, one duplicate was labelled Mahaco to trick farmers into thinking it was Mahyco (Herring 2008b). Failure to control bollworms on those plants is not a failure of Bt technology, but a failure of information in an unregulated seed market. The extent of counterfeit and spurious seed distribution is not known, but has been significant, including in troubled cotton areas such as Vidarbha.[12] Like Warangal earlier, Vidarbha has become a site of media reports of failures of Bt cotton. Some farmers who honestly believe that they have planted Bt cotton seeds have in fact been victimised by fraudulent labelling of a popular technology.

Finally, cotton fails when water is inadequate. Government agencies in India strongly advise against cotton cultivation in drought-prone marginal areas without irrigation, whether the cultivar is Bt or non-Bt. In thin red soils without irrigation, the risks of planting any cotton are high. Farmers know this, but alternatives are often less desirable. There is no evidence that addition of the Bt transgene affects drought tolerance one way or the other. Drought tolerance is a trait that would be among the very first priorities of Indian cotton farmers if biotechnology could produce it, but to date there are only distal promises, no products.

6 The Aggregate Picture

India has more land under cotton than any other country; yields before the introduction of Bt cotton were among the lowest in the world. Bt technology was meant to reduce losses to pests – hence improving harvested yields – while reducing pesticide use, resulting in improvement of farmers' incomes and reduced environmental damage. Cotton yields after the introduction of Bt hybrids have increased significantly, along with aggregate production: India has surpassed the United States as the second largest cotton-producing nation, behind China.

Bt cotton was officially approved on 26 March 2002, making India the 16th country in the world to commercialise a genetically engineered crop. In 2002, only three Bt hybrids were legally available; in 2010 there were 779 approved Bt hybrids and one open-pollinated Bt variety (from the public sector). Bt cotton hybrids diffused rapidly and widely on farms and in commercial firms' offerings. India ranked fourth in the world in area under transgenic crops in 2010, following the US, Brazil and Argentina, and ahead of Canada and China (Herring 2011). Aggregate global data have understated Indian acreage, especially in the early years, as unknown quantities of stealth Bt seeds have been in circulation. Official reduction in the trait value of Bt cotton seeds by state governments in 2006 reduced prices of government-approved hybrids by 40-60%, and thus, reduced incentives for gray-market underground breeders.

Early hybrids contained a single transgene; beginning in 2006, a "stacked gene" technology produced hybrids with two transgenes (cry1Ac and cry2Ab) to expand insect control. By 2009 more hybrids incorporated the stacked gene technology than the first generation single gene technology. By 2010, Bt cotton hybrids accounted for about 94 lakh hectares (lh) of the approximately 110 lh planted to cotton in India. Within the Bt acreage, stacked gene technology covered about 66 lh. These Bollgard II seeds are somewhat more expensive than the original single gene Bt hybrids, but farmers are evidently finding the increased cost justified by returns in the field.

Production and productivity at the national level reinforce the micro-level story of increased production and productivity. Table 3 and Figure 4 (p 51) indicate significant increases in harvested yield of cotton at the national level, even at a time when farmers of many other crops were experiencing increased difficulties in India. The jump in yields has been relatively recent. It took 36 years to double the lint production per hectare in India from 100 kg in 1950-51 to 200 kg/ha in 1986-87 (Figure 4). It took only five years for lint production per hectare to double again, after the introduction of Bt technology in cotton in 2002-03. The average yield for five-year period, preceding introduction of Bt cotton, was 203 kg/ha. The most recent estimate for 2010-11 is 518 kg/ha. Total production has increased by more than 150% over the average for the five-year period preceding introduction of Bt cotton. Though weather is always a critical factor, it seems certain that the new cotton is largely responsible for increased productivity, along with other interventions, such as the cotton technology mission.[13]

Table 3: Changes in Cotton Production and Productivity at National Level

Year	Area (Mha)	Production (Lakh bales of 170 kg each)	Yield (Kg/ha)
Five-year average ending 2002-03	8.7	104	203
2003-04	7.6	137	306
2004-05	8.8	164	321
2005-06	8.7	185	354
2006-07	9.1	226	421
2007-08	9.4	259	470
2008-09	9.4	223	419
2009-10	10.31	240	395
2010-11*	11.00	335	518

* Fourth advance estimates.
Source: Directorate of Economics and Statistics, Ministry of Agriculture.

This aggregate conclusion has been challenged. Kavita Kuruganti (2009) has presented a counterargument. Her claim was that production increases are caused by increased area under hybrids and increased area under irrigation. This

Figure 4: Cotton Per Hectare Yields since 1950 (yield in kgs/ha)

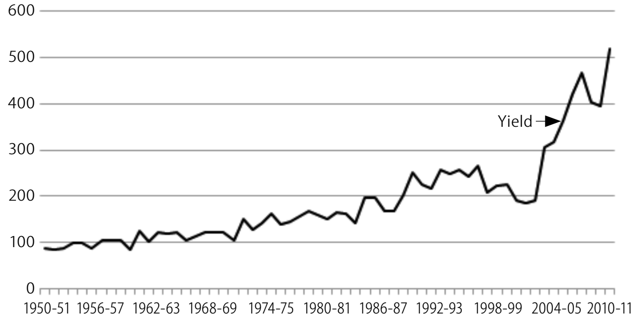
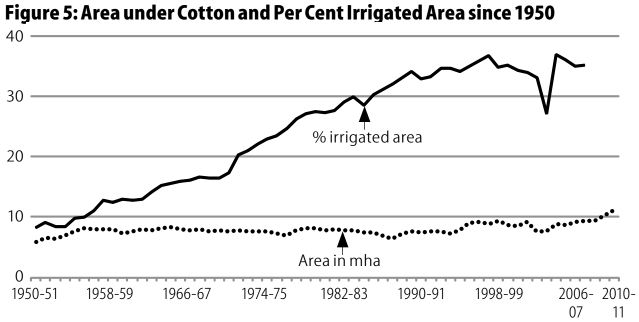


Figure 5: Area under Cotton and Per Cent Irrigated Area since 1950



Source: Directorate of Economics and Statistics, Ministry of Agriculture.

argument is not persuasive. The area under hybrids has been increasing in cotton for the last two decades and the process accelerated after introduction of Bt technology; the big jump in productivity happened only after Bt. The area under irrigation did not change sufficiently to explain so marked an increase in yields and production. Indeed, continuous increases in irrigated area in cotton did not correspond to a decisive improvement in yields until after introduction of Bt technology. After a continuous increase in the percentage of cotton area irrigated from 1951 up till the 1990s, the percentage of cotton area irrigated stabilised and has been relatively constant in the Bt period, except for a drop in 2003-04 (Figure 5). Neither area under hybrids nor cotton area irrigated can explain the dramatic increases in yields and production.

Farm-level yields and aggregate national production have understandably dominated concerns in the Bt cotton discussion, but are only part of the story. Crop success or failure has local spread effects. Bt cotton seems to have positive effects in this sense. In studies conducted by Subramanian and Qaim (2010), Bt cotton adoption increases aggregate household incomes, including those of poor and vulnerable farmers; the net effect is increasing returns to labour, especially for hired female workers.[14] Panel studies in Andhra Pradesh indicate significantly higher percentage increases in labour employment and share of wages in total costs of production, resulting from higher labour productivity.[15] Higher production means more demand for labour, since harvesting is done manually in India, unlike the situation in some other countries. More cotton production also means more economic activity in villages; crop failures, on the other hand, depress village economies whether one is a farmer or not. Landless labourers in particular are vulnerable to crop failures – they lose remunerative harvest work – but have no voice in crop technology choices.

7 Conclusions: Why Has There Been Controversy?

Much of the world believes that Prince Charles was correct in his 2008 pronouncement in New Delhi: "I blame GM crops for farmer suicides". India has been a major source of the global narrative of catastrophe. Transgenic cotton seeds in India have been characterised not only as "suicidal", but even "homicidal", and finally, "genocidal" in prominent commentaries about rural India emerging from India and subsequently diffusing through global networks and media (Herring 2009).

The catastrophe narrative is widely distributed but devoid of evidence. Field studies of Bt cotton hybrids in India demonstrate variance in outcomes, but fail to support claims of technology failure. The insect-resistance trait from the Bt transgene has generally allowed better yields of harvested cotton with less spraying of toxins. Reduced pesticide cost and better yields have improved farmer incomes. These results hold across size and social categories in both cross-sectional and longitudinal studies. The reason is that seed technology is scale-neutral, offering similar benefits to both small and large farmers. As importantly, because the technology is all contained in the seed, Bt cotton allowed "trialability": the possibility of trying out small amounts of seed at low cost and expanding planting after assessing performance (Roy 2006). Farmer behaviour is then perhaps the most telling refutation of the failure narrative: Bt cotton has spread almost universally among farmers of all size classes.

Studies may disagree, but do have a centre of gravity, a central tendency. That centre of gravity is a clear refutation of the "failure of Bt cotton" narrative. But as important as formal studies is this grounded empirics of farmers trying out new ways to cope with a periodically devastating problem. Farmer adoption and diffusion ratify most convincingly the technology behind Bt cotton. Bt genes confer no miracles, but do offer a trait that helps significantly in mitigating the effects of a major enemy of cotton – the bollworm – and the accompanying hazards of pesticide dependency: indebtedness and poisoning.

These robust results – conclusions of farmer and studies alike – have been rejected in much of the media and in some social organisations. There are two kinds of explanations: one is based on interests, the other is based on the inherent difficulty of assessing outcomes in so varied an agro-ecology as India's cotton zones. The Bt failure literature requires some explanation not only for its prominence, but also because it clashes so egregiously with farmer behaviour.

The global rifts on agricultural biotechnology have created rival networks with opposed interests (Heins 2005; Herring 2008a). Corporate interests in biotechnology promise miracle seeds; opponents have interests in demonstrating technology failure. There are markets for both narratives and interests in their production. For some NGOs, failure means affirmation of their campaigns for alternatives: organic farming and "GMO-free zones", both popular in Europe and in international advocacy networks. These NGOs can be funded to solve problems only if there are problems, or to mediate the controversy only if controversy can be sustained. Some claims of firms and organisations should then be considered strategic or instrumental in an ongoing political conflict over sustainable futures. Mass publics face daunting information costs in assessing these rival claims; distance from agriculture in middle-class populations makes assessment doubly difficult. Molecular biology is cognitively daunting. Few urban citizens know how traits are introduced into crops, or the complex determinants of yields in fields. Media reports of extreme events leave urban constituencies with considerable anxiety. A nuanced report on variable results across different Bt hybrids under different agronomic conditions will not be recognised in global advocacy venues; "complete failure" gets everyone's attention. An almost universal folk saying runs: "Where there is smoke, there is fire". Competition thus selects for extreme claims that facilitate being heard in the global cacophony.

Aside from the question of interests, field reports of failure have alternative explanations. First, confusion of traits with technology with cultivars results in a cognitive lumping contrary to agricultural practice; hundreds of distinct Bt cultivars become "GMOs" (genetically modified organism). Field studies have often failed to make the appropriate distinctions, resulting in considerable confusion (Naik et al 2005). Second, the very popularity of Bt cotton opened the door to spurious seeds: demand exceeded supply. "Genetic anarchy" of unregulated and illegal Bt hybrids muddied the waters. Many reports of Bt failure in specific fields or specific seasons must be coming from farmers who think their cotton has the cry Bt transgene protection when it does not. No studies that we know of test for spurious seeds.

More fundamentally, despite the lack of evidence, the failure narrative resonates with the penumbra of anxiety that hangs over the GMO. Reports of India's Bt failure resonate internationally because of global unease with official science bent by corporate interests and influence. In discussions of agricultural biotechnology anywhere in the world, someone invariably raises the issue of the farmer suicides in India, driven by "terminator technology" in Bt cotton. Evidence to the contrary – e g, widespread replication of illegal seeds, saving of F2 seeds, high rates of adoption – face a steep cognitive obstacle given information costs and the dominant scepticism about GMOs. Competing claims of suicide seeds and silver bullets, make evaluation of outcomes especially difficult. Ironically, a collective cultural urban bias seems to diminish the power of the numbers of those who take them most seriously: the farmers. There is curiously little attention given to the skill, experience and agency of farmers in assessing the new technology. In this case, their numbers – on yields, pesticide costs and income – accord with the central findings of the bulk of empirical work on Bt cotton. As farmers of necessity must count carefully, their numbers should count.

NOTES

1 A report published in *Science in Society*, London, by Mae-Wan Ho, was submitted to Jairam Ramesh, the then environment minister of India, urging him to stop growing Bt cotton and other GM crops in India during the Bt brinjal controversy on these grounds. See http://permaculture.org.au/2010/01/26/farmer-suicides-and-bt-cotton-nightmare-unfolding-in-india/. Similar claims were made in an American report from the New York University Law School: *Every Thirty Minutes: Farmer Suicides, Human Rights, and the Agrarian Crisis in India,* Centre for Human Rights and Global Justice (New York: NYU School of Law, 2011).
The phrase in the text comes from an article in rediff Business a rediff.com, "India says no to Bt brinjal, for now", 9 February 2010: "Bt cotton has already been declared a farce with crop failures and mass suicides of farmers in India". We cite these stories not for their authority, but as an indication of the diffusion of the narrative.

2 Health and environmental effects in general are overdetermined and difficult to assess, especially in the short term. For an ove-view of the range of issues in the controversy, see Herring (2007a, 2007c); Review of Agrarian Studies (2011). On ethics specifically, see Nuffield Council (2004).

3 Examples of studies finding support for the success story include Naik (2001); Qaim and Zilberman (2003); Neilsen (2004); Bambawale et al (2004); Bennett et al (2004); Naik et al (2005); Gupta and Chandak (2005); Patil, Basavaraj and Hanchimal (2007); Dev and Rao (2006); Gandhi and Namboodiri, (2006); Bennett et al (2006); Narayanamoorthy and Kalamkar (2006); Roy, Herring and Geisler (2007); Sadashivappa and Qaim (2009); Subramanian and Qaim (2009, 2010); Rao and Dev (2009; 2010).

4 Among studies indicating failure, Sahai (2003), Sahai and Rahman (2003); Shiva and Jafri (2004) and Qayum and Sakkhari (2005) gained prominence. For discussion of field studies, see APCoAB (2006); Gruère et al (2008); Gruère (2011); Herring (2008b).

5 Review of a smaller sample of peer-reviewed studies resulted in the same pattern and very similar arithmetic averages on the major variables of agro-economic interest. See also Gruère 2011.

6 Glenn Stone refers to this as a "craze" for Bt cotton in Warangal. One consequence was counterfeit seeds being sold as Bt, since the supply of genuine Bt was less than the demand (Herring 2008b).

7 For details of method and participants Herring 2008b. Interviews with Dr Ranga Rao, of Prabhat Seeds, Dr Satynarayana of Nuziveedhu Seeds, Dr P Satish Kumar of Prabhat Agribiotech, Hyderabad, 13 December 2006.

8 Stone's use of the word "craze" indicates his belief that adoption of Bt cotton was not entirely rational farmer behaviour. His subsequent work in the district (Stone 2010) confirmed higher yields, reduced pesticide use but remained concerned about farmer adaptation to new technology.

9 Though hybrid seeds are not saved in general, some farmers in Gujarat saved F2 Bt hybrid seeds in the early years when Navbharat 151 was quashed by the GEAC and became unavailable in Gujarat. F2 seeds were in these cases used straight from the gin as "loose seeds" (Roy et al 2007).

10 The only study we know is Bambawale et al 2004; Bollgard MECH-162 was compared to the isogenic non-Bt MECH 162 and a conventional hybrid. Their study used a participatory field trial to test meaningfully paired hybrids with and without integrated pest management (IPM).

11 How the inserted gene affects the genome is the subject of much research. Despite the concern about GMOs, a major recent review of 130 research projects funded by the EU found that there is no scientific evidence that transgenesis as a means of modifying a plant's genetic material is more risky than "conventional plant breeding technologies" (European Commission Directorate-General for Research 2010).

12 A field kit developed by the Central Institute for Cotton Research in Nagpur allows testing whether or not the plants' tissue actually contains the cry protein produced by the transgene. Dr K R Kranthi, the chief scientist there, believes contamination and false labelling to be quite extensive. For discussion, see Herring and Kandlikar 2009.

13 The CACP attributes 50% of the increase in production and productivity to the introduction of Bt cotton (GoI 2008)

14 See Subramanian and Qaim (2009, 2010).

15 See Rao and Dev (2010) Chapters 5 and 7 for details.

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