Agricultural Economics Research Review 2020, 33 (1), 53-60
DOI: 10.5958/0974-0279.2020.00006.3

How does Bt cotton perform in rainfed areas?

A Narayanamoorthy*, C Renuka, and K S Sujitha

Department of Economics and Rural Development, Alagappa University,
Karaikudi-630 003, Tamil Nadu, India

*Corresponding author: narayana64@gmail.com

Abstract Bacillus thuringiensis (Bt) cotton is the only genetically modified crop permitted for commercial cultivation in India. We use farm-level data from 150 sample farmers cultivating cotton in rainfed areas in Tamil Nadu, a state in India, and conduct multiple regression analysis to compare its economic performance with that of non-Bt cotton. Compared to non-Bt cotton cultivated in a similar environment, Bt cotton reduces pesticide consumption by about 28%. Since Bt cotton is resistant to bollworm infestation, productivity is higher by 34% and profitability by 98%.

Keywords Bt cotton; cotton productivity; pesticide use; rainfed crops

JEL codes Q12, Q16, Q18

Cotton contributes significantly to the development of both the agricultural and industrial (textile) sectors in India. The crop is grown mainly in Maharashtra, Gujarat, Andhra Pradesh, and Tamil Nadu. With a cultivated area of 12.29 million hectares (mha) in 2015–16, cotton accounts for 11% of the net cropped area (GoI 2017b). While making up 33% of the world's total acreage, India contributes only 23% of world production (GoI 2017a; James 2014), and productivity is one of the lowest in the world. In India, cotton is cultivated predominantly under rainfed conditions, which increase the risk in getting yield because of uncertainty in rainfall and reduced moisture availability—about 67% of the cotton crop was cultivated under rainfed conditions even during 2015–16 (GoI 2017b)—and the chronic and severe infestation of bollworm and other pests destroys 50–60% of the yield (Lalitha and Ramaswami 2007; Mayee et al. 2002). Also, indiscriminate pesticide use raises cultivation cost. Bacillus thuringiensis (Bt) cotton was developed to reduce pesticide consumption (Ranganathan, Gaurav, and Halder 2018) and overcome the bollworm problem (Mayee et al. 2002), and the Government of India permitted commercial cultivation in March 2002.

There was shrill invective both for and against the hybrid, and bones of contention have included intellectual property, environmental safety, ethics, and even field performances of Bt hybrid. Nevertheless, studies showed that compared to non-Bt cotton, Bt cotton can significantly reduce bollworm attack and cultivation cost and improve crop yield (Mayee et al. 2002), and since its introduction Bt cotton has emerged as an effective alternative to traditional cotton varieties by controlling bollworm attack and, thereby, improving yield and income. Bt cotton has been adopted quickly, and cotton production in India grew more than four times—from 8.6 million bales in 2002–03 to 35.9 million bales in 2013–14—before stagnating recently (GoI 2017b), and the total area under Bt cotton increased from a mere 29,000 hectares in 2002–03 to 10.682 million hectares in 2015–16. Presently, Bt cotton accounts for about 90% of India's total cotton area (GoI 2017a).

After Bt cotton was introduced in India, quite a few studies analysed the impact of Bt cotton on pesticide use, cost of cultivation, and productivity. Studies carried out in Maharashtra and Andhra Pradesh show that Bt cotton does not reduce pesticide use (Sahai and

Rahman 2003; Shiva, Emani, and Jafri 1999; Qayum and Sakkhari 2003), but quite a few studies find that it does reduce pesticide use marginally (Mayee et al. 2002; Pray et al. 2001; Huang et al. 2002; Ismael, Bennett, and Morse 2002; Qaim et al. 2006; Subramanian and Qaim 2009; Ashok et al. 2012). Most studies show that the cost of cultivating Bt cotton is higher than that of non-Bt seeds (Shiva, Emani, and Jafri 1999; Pray et al. 2001; Iyengar and Lalitha 2002; Yamaguchi and Harris 2003; Narayanamoorthy and Kalamkar 2006; Gandhi and Namboodiri 2006). A few studies show that the yield of Bt cotton is higher than that of non-Bt cotton (Chaturvedi 2002; Pray et al. 2001; Ismael et al. 2002; Huang et al. 2002; Dong, Tong, and Zhang 2004; Bennet et al. 2006; Dev and Rao 2007; Narayanamoorthy and Kalamkar 2006; Loganathan et al. 2009; Kiresur and Ichangi 2011; Ashok et al. 2012), but some studies find either a reduction or an insignificant increase in yield (Shiva, Emani, and Jafri 1999; Sahai 2002).

These studies do not find that the impact of Bt cotton is uniform because most of these studies have some methodological deficiency. Few studies only specify whether Bt cotton is cultivated under irrigated conditions or rainfed. If a crop is irrigated, its economic performance is expected to be better than under rainfed conditions because the risk in getting output is lower (Narayanamoorthy, Suresh, and Alli 2015). Moreover, the impact of Bt cotton cannot be judged clearly if the data used for analysis is from both irrigated and rainfed areas. In India, Bt cotton is cultivated predominantly under rainfed conditions (GoI 2017a) and, therefore, one must use data from rainfed areas to assess the real economic performance of Bt cotton. This study attempts to find out the input use pattern, cultivation cost, productivity, and profitability of Bt cotton cultivated under rainfed conditions.

Study area and method

The study used, mainly, data from a field survey conducted in Salem district of Tamil Nadu, which is among the top 10 cotton-cultivating states in India. As per the data of 2014–15, the state had cultivated about 190,000 hectares of cotton (GoI 2017b). Of the 16 Bt cotton–growing districts in Tamil Nadu, Salem district was selected purposively as it cultivates cotton largely under rainfed conditions (*Season and Crop Report of Tamil Nadu: 2014–15*). Information on the adoption of Bt cotton is not available for each district of Tamil Nadu, and officials of the Department of Agriculture in Salem district helped us to select the three study villages and sample farmers.

We selected three villages (Attur, Kalpagnur, and Akknichettipalayam) from Attur Block to study Bt cotton and two villages (Pudupalayam and Rajapalayam) from Veerapandi Block to study non-Bt cotton. Ideally, we would have selected both Bt and non-Bt sample farmers from the same villages to reduce differences in soil quality and other agro-economic factors between the two groups of farmers, but the required number of non-Bt sample farmers were not available in the villages where Bt cotton was cultivated predominantly. However, the agroecological conditions are similar in the selected blocks.

We selected 150 sample farmers; 100 of them grew Bt cotton and 50 grew non-Bt cotton. The study aims to evaluate the performance of Bt cotton cultivated under rainfed conditions; thus, we selected farmers cultivating Bt and non-Bt cotton under rainfed conditions only. We followed the purposive sampling method to select the sample farmers from both groups. The field-level information on Bt and non-Bt cotton cultivation was collected using a pre-tested interview schedule pertaining to the 2016 kharif season. We compared Bt and non-Bt cotton farmers on several economic parameters to study the benefits of Bt cotton. One of the objectives of this study is to find out the productivity of Bt cotton, considered to be its major benefit. To study its productivity, we estimated the following linear regression model:

$$\text{Yield} = a + b_1\text{EDU} + b_2\text{LHS} + b_3\text{FIE} + b_4\text{FER} + b_5\text{FYM} + b_6\text{PES} + b_7\text{VAD} + \mu \quad \ldots(1)$$

where, yield is productivity of cotton (quintal per acre); EDU is level of education of the farmers involved in agriculture (in years); LHS is the landholding size (in acre); FIE is the farm improvement expenditure (in rupee per acre); FER is the expenditures on fertilizers (in rupee per acre); FYM is the expenditure on farm yard manure (in rupee per acre); PES is the expenditure on pesticides (in rupee per acre); VAD is variety dummy (1 for Bt cotton; 0 for non-Bt cotton); and μ is the error term.

Table 1 Characteristics of Bt and non-Bt cotton sample households

Characteristics	Bt Households	Non-Bt Households	Test of significance of mean value
Number of sample households	100	50	—
Average size of family	4.33	4.22	NSD
Average farming experience (years)	25.26	30.18	NSD
Average education (years)	8.35	6.24	**
Household with agricultureas main occupation (%)	100.00	100.00	—
Average land size (acre)	3.06	2.40	**
Foodgrains area to GCA (%)	16.50	37.83	**
Non-foodgrains area to GCA (%)	6.36	10.03	**
Cotton area to GCA (%)	77.13	52.89	**
Cropping intensity (%)	171.67	106.14	**

Notes GCA is gross cropped area; ** is significant difference at 5% level; NSD is no significant difference.
Source Field survey data.

The main aim of this analysis is to find out the impact of Bt hybrid on productivity; therefore, the variety dummy is used to differentiate Bt farmers from non-Bt farmers. Farmer's education (EDU) is essential for adopting any new technological component in crop cultivation; therefore, it is used in the model. Inputs such as fertilizers, FYM, pesticides, and farm improvement expenditure (FIE) are needed to raise the productivity of any crop; therefore, these variables have to be incorporated in any model that studies crop productivity. The landholding size (LHS), an important factor of crop productivity, is used to reflect the resource position of farmers. Among the variables included in the regression model, the variety dummy (Bt = 1; non-Bt = 0) is expected to significantly influence the productivity of cotton.

Results and discussion

Characteristics of sample farmers

The personal characteristics of Bt farmers are somewhat different from that of non-Bt farmers (Table 1). Young farmers tend to adopt any new technology earlier than old farmers; therefore, it was expected that Bt cotton growers would have less farming experience than non-Bt cotton growers. This expectation is borne out by the study: Bt cotton–cultivating households average 25.26 years of farming experience and non-Bt farmers average 30.18 years. Bt farmers are better educated than non-Bt farmers; this is expected, because educated farmers are early adopters of any new technology. Land quality and landholding size also determine the adoption of any new technology in agriculture. It was expected that the average landholding size of Bt cotton growers would be higher than that of non-Bt growers; this expectation also turned out to be true. We now turn to the impact of Bt cotton on economic parameters.

Input use pattern

Bt cotton is more cost-intensive than the conventional hybrid variety, and the seed company claims that Bt cotton reduces the infestation of pests, especially bollworm, and substantially reduces pesticide use. Therefore, we looked for differences in the input use pattern between Bt and non-Bt cotton growers, and found that except for seeds and pesticides, input use is considerably higher for Bt cotton cultivators (Table 2).

In the study area, Bt cotton farmers used substantially higher amounts of yield-increasing inputs such as fertilizers—225 kg of NPK fertilizers per acre, over 15% more than the 195 kg per acre used by non-Bt cotton growers—and about 67% more farm yard manure. Most Bt cotton cultivators are progressive farmers and they use more of yield-increasing inputs. Both Bt and non-Bt farmers followed the recommended seed rate. Bt cotton cultivators used around 490 gram per acre, and non-Bt cultivators used around 2,200 gram per acre. The difference is explained by the landholding size of the cotton cultivators and the difference in spacing crops.

Table 2 Inputs application for Bt and non-Bt cotton

(Units/acre)

Inputs	Bt cotton	Non-Bt cotton	% over non-Bt cotton
Manual labours (days)	114.56	90.08	27.17
Tractor (hours)	4.37	3.58	22.06
Seed (gram)	490	2200	-77.72
Fertilizers (kg)			
Urea (N)	97.63	86.12	13.36
Phosphate (P)	83.28	65.30	27.53
Potash (K)	60.00	43.60	37.61
Total NPK (kg)	225.05	195.02	15.39
FYM (cart load)	3.44	2.06	66.99
Pesticides (litre)	5.02	6.97	-27.97

Source Field survey data

Compared to non-Bt cotton farmers, Bt cotton farmers reduced pesticide use by about 28% (Table 3) and used less number of spray/time (4.44); non-Bt cotton growing farmers used 6.14. Bt cotton farmers used pesticides mostly to control sucking pests and, therefore, minimized pesticide use. At the time we conducted the survey, farmers reported the emerging problem of pink bollworm attack in Bt cotton.

Cost of cultivation

We attempted to study the cost of cultivating Bt cotton by comparing the cost of each operation for Bt and non-Bt cotton to assess the difference, and we found that it costs considerably more to cultivate Bt cotton (Table 4). Cultivating Bt cotton costs Rs 27,365 (cost A2+FL) per acre on average, nearly 8% more than the

Table 4 Cultivation cost by operation (cost A2 + FL) for Bt and non-Bt cotton

(Rs/acre)

Operation	Bt cotton	Non-Bt cotton	% over non-Bt cotton
Preparatory works	710.00 (2.59)	644.00 (2.53)	10.24
Ploughing	4239.40 (15.49)	3516.86 (13.85)	20.54
Seed	1025.45 (3.74)	557.56 (2.19)	83.91
Sowing	787.20 (2.87)	1044.00 (4.11)	-24.60
Fertilizers plus labour	4550.00 (16.62)	4313.90 (16.99)	5.47
FYM plus labour	3059.70 (11.18)	2158.50 (8.50)	41.75
Pesticides plus labour	4298.45 (15.70)	5245.58 (20.66)	-15.08
Weeding and inter-culture	2045.40 (7.47)	2444.40 (9.62)	-18.05
Harvesting (picking)	4933.00 (18.02)	4133.60 (16.28)	19.33
Transport and marketing	1717.00 (6.27)	1326.00 (5.22)	29.48
Total cost	27365.60 (100.0)	25384.40 (100.0)	7.80
Test of significance of mean in total cost	**		

Notes Figures in brackets are percent to total cost of cultivation; ** significant difference at 5% level

Source Field survey data

Table 3 Number of spray and quantity of pesticides used in Bt and non-Bt cotton

(Units/acre)

Particulars	Btcotton	Non-Bt cotton	% over non-Bt cotton	Test of significance of mean
Number of spray	4.44	6.14	-27.69	**
Quantity per spray (milli litre)	800.00	1100.00	-27.27	**
Quantity of pesticides used (litre)	5.02	6.97	-27.97	**
Cost of pesticides (Rs)	2855.90	3679.49	-22.38	**

Note ** Significant difference at 5% level

Source Field survey data

Table 5 Productivity of Bt and non-Bt cotton

Particulars	Productivity (quintal/acre)	Productivity range (quintal/acre)
Bt cotton	7.50	5 to 12
Non-Bt cotton	5.60	4.5 to 7
Absolute increase over non-Bt (quintal)	1.90	
Increase over non-Bt cotton (%)	33.92	
Test of significance of mean productivity	Significant difference at 5% level	

Source Field survey data

Rs 25,384 per acre on average for non-Bt cotton. What explains this difference? First, the seed cost of Bt cotton is Rs 1,025 per acre, almost double that of non-Bt cotton seed (Rs 557 per acre). Second, Bt cotton growers incur about 47% higher expenditure on fertilizers and farm yard manure. Third, Bt cotton is more productive, and therefore harvesting, transport, and marketing cost more.

Productivity of Bt and non-Bt cotton

One of the advantages of Bt hybrid is that it is capable of increasing productivity. Earlier studies, too, show that Bt cotton can increase productivity substantially compared to the conventional hybrid non-Bt cotton. The average productivity of Bt cotton is 7.50 quintals per acre, about 34% more than the 5.60 quintals per acre for non-Bt cotton (Table 5). Bt cotton is more productive because the bollworm attack was very low and, therefore, there was little crop damage; bollworms heavily damaged the non-Bt cotton crop of many farmers although they applied much more of pesticides. Second, each Bt cotton plant produced more bolls. Third, Bt cotton growers used more of yield-increasing inputs, which may have influenced productivity.

We used regression analysis to find out the relative contribution of the factors of productivity. We expected that all the seven variables used in Equation 1 contribute to the productivity of cotton one way or the other, but only the variety dummy appears to have contributed significantly (Table 6); it turned out to be the most significant (highest coefficient value) in raising productivity. This is as expected, because almost all Bt cotton cultivators in our sample have harvested substantially higher productivity than that of non-Bt counterpart. The use of fertilizers and farm yard manure is higher in Bt cotton, and all these factors might have contributed to increasing productivity. The influence of all other variables, including landholding size (LHS) of farmers, on productivity of cotton is insignificant, which is a plausible result.

Table 6 Determinants of productivity of cotton: regression results

Variables	Coeffi-cients	't' value
Variety dummy (1=Bt and 0= Non-Bt)	1.498	8.596 [a]
Education (years)	.0004	.0296 [NS]
Fertilizers (Rs)	.0002	1.535 [d]
Farm improvement expenditures (Rs)	-4.788	-.540 [NS]
Farm yard manure (cart load)	.0001	2.418 [a]
Landholding size (acre)	-.0273	-.536 [NS]
Pesticides (Rs)	.0002	2.243 [b]
Constant	3.778	4.283 [a]
R^2	0.486	-
Adjusted R^2	0.461	-
F value	19.183	-
D-W value	2.02	-
N	150	-

Notes a and b are significant at 1% and 5% respectively; NS is not significant.
Source Computed using field survey data.

Profitability of Bt and non-Bt cotton

Profitability is expected to be very high from Bt cotton cultivation mainly because productivity is higher, which is observed in this study as well, but the existing studies show divergent results. We attempted to find out the difference in profitability between Bt and non-

Table 7 Gross value of production and profit from Bt and non-Bt cotton

Particulars	Bt	Non-Bt	% over non-Bt	Test of significance of mean
Gross value of production (Rs per acre)	43138	33319	29.46	**
Gross cost of cultivation (Rs per acre)	27365	25384	7.80	**
Cost of production (Rs per quintal)	3648	4532	-19.50	—
Profit (Rs per acre)	15773	7935	98.77	**
GVP:GCC	1.57	1.31	19.84	—

Notes GVP is gross value of production; GCC is gross cost of cultivation; ** is significant difference at 5% level
Source Field survey data

Bt cotton. For computing profitability, we deducted the gross cost of cultivation (GCC) from the gross value of production (GVP) per acre; we estimated GVP by multiplying the productivity of cotton with the output price (per quintal) received by each sample farmer (Table 7). The profit from cultivating Bt cotton crop is Rs 15,773 per acre, 98% more than the Rs 7,935 per acre for non-Bt cotton.

How is the profit so much higher? The yield of Bt cotton is substantially higher, and the higher productivity raises its cost efficiency (Table 7): only Rs 3,648 per quintal, compared to Rs 4,532 per quintal for non-Bt cotton. The income and expenditure analysis suggests that the profit from cultivating Bt cotton is considerably higher than non-Bt cotton even in rainfed areas.

Conclusions

This study attempted to find out the economic impact of cultivating Bt cotton in rainfed conditions in Tamil Nadu by comparing it with non-Bt cotton. We found that the cost of cultivating Bt cotton crop is more than that of non-Bt cotton. Bt cotton farmers can reduce pesticide use, in terms of both number of sprays and quantity, and incur much less expenditure on account of pesticides for Bt cotton. Bollworm infestation is less in Bt cotton, and productivity was about 34% higher than non-Bt cotton. The increased productivity helped Bt cotton farmers realize about 98% higher profit. The results of the study suggest that productivity and profit from Bt cotton cultivation is substantially higher than from conventional hybrid cotton even in rainfed areas.

Bt hybrid is beneficial, but farmers say that Bt cotton seeds cost much more than non-Bt cotton seeds, and the high cost constraints adoption, especially among resource-poor farmers (marginal and small landholders). The government should promote research and development in transgenic cotton seed production in the public sector to bring down the cost of Bt cotton seeds.

Most Bt cotton farmers continue to use pesticides in large quantities because of poor awareness and their fear of bollworm attacks, but pesticide overuse increases the cost of cultivation and private cost and also the social cost by damaging the environment. Therefore, seed companies that produce and sell Bt varieties must counsel farmers on optimal pesticide use.

This study finds that the return from Bt cotton crop is considerably higher than that of non-Bt cotton crop, but it is difficult to pronounce that the same return can be realized from the entire state of Tamil Nadu or from all rainfed regions in India. The relative return from Bt cotton crop can go down in a rainfed area if the adoption of yield-increasing inputs or practices is less than the level in this study. To establish the economic benefits of Bt cotton cultivation in India, further studies are needed on varieties of Bt cotton and in rainfed areas in different regions.

An emerging problem is the recent, large-scale infestation of pink bollworm in Bt cotton. The current BG II seed seems to be ineffective against pink bollworm. Therefore, studies need to be conducted on the productivity and profitability of BG II, especially in rainfed areas.

Acknowledgements

We are grateful to the anonymous referee for making very useful comments on an earlier version of the paper. We are also grateful to Alagappa University for providing research assistance from the Rashtriya

Uchchattar Shiksha Abhiyan (RUSA) Phase 2.0 Scheme for writing this paper. The views expressed in this paper are our own.

References

Ashok, K R, K Uma, M Prahadeeswaran, and H Jeyanthi. 2012. Economic and environmental impact of Bt cotton in India. *Indian Journal of Agricultural Economics* 67: 405–28. https://ideas.repec.org/a/ags/inijae/204824.html

Azhar, R A. 1991. Education and technical efficiency during the green revolution in Pakistan. *Economic Development and Cultural Change* 39: 651–65. doi/10.1086/451894

Bennett, R M, U Kambhampati, S Morse, and Y Ismael. 2006. Farm-level economic performance of genetically modified cotton in Maharashtra, India. *Review of Agricultural Economics* 28: 59–71. doi:10.1111/j.1467–9353.2006.00273.x

Chaturvedi, S. 2002. Agricultural biotechnology and new trends in IPR regime: challenges before developing countries. *Economic and Political Weekly* 37: 1212–22. epw.in/journal/2002/13/review-agriculture-review-issues-specials/agricultural-biotechnology-and-new-trends

Commission for Agricultural Costs and Prices, Ministry of Agriculture, Government of India. 2013. *Report of the commission for agricultural costs and prices*., New Delhi. cacp.dacnet.nic.in/

Department of Economics and Statistics, Government of Tamil Nadu. 2015. *Season and Crop Reports Tamil Nadu: 2014–15*, Chennai. tn.gov.in/deptst/agriculture.pdf

Dev, S M and N C Rao. 2007. Socio-economic impact of Bt cotton. Monograph 3 November, Centre for Economic, and Social Studies, Hyderabad. 183.82.4.93:81/cess_version1/wp-content/uploads/2019/10/Monograph-No.03.pdf

Directorate of Cotton Development, Ministry of Agriculture and Farmers Welfare, Government of India. 2017a. *Status paper of Indian cotton*. New Delhi. nfsm.gov.in/StatusPaper/Cotton2016.pdf

Directorate of Economics and Statistics, Ministry of Agriculture, Government of India. 2017b. *Agricultural statistics at a glance 2017*. New Delhi. https://eands.dacnet.nic.in/PDF/Agricultural%20Statistics%20at%20a%20Glance%202017.pdf?

Dong, H W, Li W Tang, and D Zhang. 2004. Development of hybrid Bt cotton in China: a successful integration of transgenic technology and conventional techniques. *Current Science* 86: 778–82. www.jstor.org/stable/24109134

Gandhi, V P and N V Namboodiri. 2006. The adoption and economics of Bt cotton in India: preliminary results from a study. Working Paper 20069–04, Indian Institute of Management, Ahmedabad, India. iimahd.ernet.in/publications/data/20069–04_vgandhi.pdf

Huang, J R, Hu C Fan, C E Pray, and S Rozelle. 2002. Bt cotton benefits, costs, and impacts in China. *AgBioForum* 5: 153–66. agbioforum.org/v5n4/v5n4a04-huang.htm

Ismael, Y, R Bennett, and S Morse. 2002. Benefits from Bt cotton use by small holder farmers in South Africa. *AgBioForum* 5: 1–5. agbioforum.org/v5n1/v5n1a01-morse.htm

Iyengar, S and N Lalitha. 2002. Bt cotton in India: controversy visited. *Indian Journal of Agricultural Economics* 57: 459–66. doi: 10.22004/ag.econ.297897

James, C. 2014. *Global status of commercialized biotech / GM crops: 2014*. ISAAA Brief No. 49, International Service for the Acquisition of Agri-Biotech Applications (ISAAA), Ithaca, NY. isaaa.org/resources/publications/briefs/49/download/isaaa-brief-49–2014.pdf

Kiresur, V R and M Ichangi. 2011. Socio-economic impact of Bt cotton—a case study of Karnataka. *Agricultural Economics Research Review* 24: 67–81. doi: 10.22004/ag.econ.109418

Lalitha, N and B Ramaswami. 2007. Pesticides use pattern among cotton cultivators in Gujarat. In *Frontiers of agricultural development in Gujarat*, ed R Dholakia, 77–98. Centre for Management in Agriculture, Indian Institute of Management, Ahmadabad, India.isid.ac.in/~bharat/Research/Pestcides_Use_Pattern_among_Cotton_Cultivation.pdf

Loganathan, R, R Balasubramanian, K Mani, and S Gurunathan. 2009. Productivity and profitability impact of genetically modified crops—an economic analysis of Bt cotton cultivation in Tamil Nadu. *Agricultural Economics Research Review* 22: 331–40. doi: 10.22004/ag.econ.57472

Lockheed, E M, D T Jamison, and L J Lau. 1980. Farmers' education and farm efficiency: a survey. *Economic Development and Cultural Change* 29: 37–76. https://econpapers.repec.org/scripts/redir.pf?u=http%3A%2F%2Fdx.doi.org%2F10.1086%2F451231;h=repec:ucp:ecdecc:v:29:y:1980:i:1:p:37-76

Mayee, C D, P Singh, A B Dongre, M R K Rao, and S Raj. 2002. Transgenic Bt cotton. Technical Bulletin 22, Central Institute For Cotton Research, Nagpur. cicr.org.in/pdf/transgenic_bt_cotton.pdf

Narayanamoorthy, A. 2000. Farmers' education and productivity of crops: a new approach. *Indian Journal of Agricultural Economics* 55: 511–19. doi: 10.22004/ag.econ.297769

Narayanamoorthy, A and S S Kalamkar. 2006. Is Bt cotton cultivation economically viable for Indian farmers? an empirical analysis. *Economic and Political Weekly* 41: 2716–24. epw.in/journal/2006/26/review-agriculture-review-issues-specials/bt-cotton-cultivation-economically-viable

Narayanamoorthy, A, R Suresh, and P Alli. 2015. Is the role of irrigation in agricultural output in India?: a district-wise study of six time points. *Indian Journal of Agricultural Economics* 70: 333- 49. doi: 10.22004/ag.econ.230068

Pray, Carl, D Ma, J Huang, and F Qiao. 2001. Impact of Bt cotton in China. *World Development* 29: 813- 25. doi.org/10.1016/S0305–750X(01)00010–9

Qaim, M, A Subramanian, G Naik, and D Ziberman. 2006. Adoption of Bt cotton and impact variability: insights from India. *Review of Agricultural Economics* 28: 48–58. https://doi.org/10.1111/j.1467-9353.2006.00272.x

Qayum, A, and K Sakkhari. 2003. Bt cotton in Andhra Pradesh – A three year assessment, Andhra Pradesh. Hyderabad: Deccan Development Society and Permaculture Association of India. ddsindia.com/www/PDF/BT_Cotton_-_A_three_year_report.pdf

Ranganathan, T S, Gaurav, and I I Halder. 2018. Pesticides usage by cotton farmers in India: changes over a decade. *Economic and Political Weekly* 53: 43–51. epw.in/journal/2018/19/special-articles/pesticide-usage-cotton-farmers-india.html

Sahai, S. 2002. Bt cotton: confusion prevails. *Economic and Political Weekly* 37: 1973–74. epw.in/journal/2002/21/commentary/bt-cotton-confusion-prevails.html

Sahai, S, and S Rahman. 2003. Performance of Bt cotton: data from first commercial crop. *Economic and Political Weekly* 38: 3139–41. epw.in/journal/2003/30/commentary/performance-bt-cotton.html

Schultz, T W. 1964. *Transforming traditional agriculture.* Yale University Press, New Haven, USA**.** trove.nla.gov.au/version/32352964

Shiva, V, A Emani, and A H Jafri. 1999. Globalisation and threat to seed security: case of transgenic cotton trials in India. *Economic and Political Weekly* 34: 601–13. epw.in/system/files/pdf/1999_34/10–11/Globalisation_and_Threat_to_Seed_Security.pdf

Subramanian, A and M Qaim. 2009. Village-wide effects of agricultural biotechnology: the case of Bt cotton in India. *World Development* 37: 256–67. doi:10.1016/j.worlddev.2008.03.010

Yamaguchi, T, and C K Harris. 2003. The economic hegemonization of Bt cotton discourse in India. Working Paper 178, July, Institute of Rural Management, Anand, Gujarat, India. irma.ac.in/uploads/randp/pdf/679_66361.pdf

Received: January 2019 Accepted: November 2019