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Research Article

Impact of Bt cotton technology in an Indian cotton production system: A comparative econometric analysis between Maharashtra and Tamil Nadu

R. Gayathri
Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore (Tamil Nadu), India
K. R. Karunakaran*
Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore (Tamil Nadu), India

*Corresponding author. Email: krkaruna@gmail.com

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Abstract
Cotton is one of India's most important commercial crops, known as the "White Gold." India has the largest area under cotton production with comparatively low productivity, owing to the enormous area under rainfed agriculture with insufficient input supply, implying inefficient resource usage. The present study measures the resource use efficiency and technical efficiency of Bt cotton production in Tamil Nadu in comparison with one of the major cotton-producing states, Maharashtra. The resource use efficiency was calculated using the Cobb–Douglas production function, and the stochastic frontier approach is deployed to estimate technical efficiency. Resource use efficiency analysis indicated that the majority of resources are being used at suboptimal levels, and there is the potential to increase cotton production by reaching the most profitable level of input use. However, frontier analysis confirmed that production was inefficient, with a greater gap in which both Tamil Nadu and Maharashtra, particularly small and marginal farms, need to be addressed to increase production and farm income. The results indicated that the mean technical efficiency among Bt and non-Bt farmers was 94 % and 76 % in Tamil Nadu and 97 % and 74 %, implying the potential to increase cotton production with the current level of resources and technology. This study suggested a development policy aimed at stimulating extension activity through motivation to provide rural farm households with the necessary farm management skills to boost productivity].

Keywords: Bt Cotton, Cobb–Douglas Production Function, Frontier approach, Resource Use Efficiency, Technical Efficiency

INTRODUCTION

Cotton is one of the most important cash crops, accounting for approximately one-fourth of worldwide fibre production. India also boasts the distinction of possessing the world's largest cotton-growing area, at approximately 13 million hectares. Cotton is a vital crop for India's long-term economic viability and the livelihood of the country's cotton farmers. Cotton yarn is produced and exported in enormous quantities in India. The textile sector in India generates approximately 5% of the country's GDP, 14% of industrial production, and 11% of total export revenues. After agriculture, the industry employs approximately 51 million people directly and indirectly employs 68 million people, including unskilled women, making it the country's second-largest employer. By 2021, the textile sector is anticipated to be worth $223 billion (Cotton Industry and Exports, IBEF, 2021.)

Cotton continues to be the preeminent and most preferred fibre among Indian textile mills as the primary raw material for the industry. Cotton production, marketing, processing, and exports provide a living for approximately 60 million people worldwide (Chockalingam, 2015). India occupies first place in the world in terms of acreage under cotton and cotton production. All four types of cultivated cotton, Gossypium arboreum and herbaceum (Asian cotton), G. barbadense (Egyptian cotton), and G. hirsutum (American Upland cotton), are grown in India. *Gossypium hirsutum* accounts for 88% of hybrid cotton production in India, and G. hirsutum is the source of all contemporary

Bt cotton hybrids (Ministry of textiles, GoI, 2017). India is also the only country in the world that commercially farms four cultivated cotton species, as well as their intra- and interspecific hybrids (P. Singh and Kairon, 2001). Currently, the majority of the country's cotton is produced in eleven major cotton-growing states, which are divided into three zones: the Northern Zone (Rajasthan, Punjab and Haryana), Central Zone (Orissa, Gujarat, Madhya Pradesh and Maharashtra), and Southern Zone (Telangana, Tamil Nadu, Andhra Pradesh and Karnataka). (Chockalingam, 2015).

Globally, cotton was harvested in 34.96 million hectares in 2019. Out of all countries, India has emerged as the largest cotton cultivator in the world, where the country alone accounted for approximately 39 % of world cotton acreage and 24 % of world cotton production in 2019. India is the second largest consumer of cotton (after China), uses 76 % of its production. India is the third largest exporter of cotton (after the USA & Brazil).

Bt cotton introduction has amplified cotton yield, and there has been a marked improvement in the quality of Indian cotton over the years. Indian cotton is now more desirable in the global cotton trade. There has been a paradigm shift in the Indian cotton production, textile industry and export of cotton and textiles mainly due to development initiatives taken during recent years, i.e., a huge number of ginning and pressing facilities are being modernized. Market yard development and modernization Traditional methods of visual assessment for cotton quality are giving way to scientific cotton testing on HVI machines. Over time, there has been a significant decline in pollution levels (Agarwal, 2007). Significant progress have been made in increasing yield and production since the Government of India launched the Cotton Technology Mission in February 2000 through the development of high-yielding varieties, appropriate technology transfer, improved farm management practices, and increased area under cultivation of Bt cotton hybrids, among other things. All these initiatives resulted in enormous cotton production of good quality since the introduction of Bt cotton. (National Cotton Scenario, CCI, 2022). However, the yield per hectare, which had been stable for many years at approximately 300 kg/ha, surged to 506 kg in 2017-18 and reached its maximum level of 566 kg per hectare in 2013-14. Despite the fact that the country's per hectare output remains below the world average of 762 kg per hectare, technological breakthroughs in cotton cultivation in the country have the potential to bring the country's present productivity level closer to the world average in the near future. (*National Cotton Scenario*, 2022) Among the major cotton-producing countries, India had a lower yield rate per hectare, i.e., 464 kg per hectare, in 2019-20.

Efficiency in agricultural production mainly depends upon better management of available limited resources. In achieving an optimal level of production, resource use efficiency plays a crucial role. When an input is put to the best potential use at the lowest possible expense, it is said to be efficiently utilized. Hence, the question of allocation of resources needs to consider sustainability, resource use efficiency and optimization of crop plans across regions and production environments. Resource use efficiency in agriculture plays a major role in determining the yield and profit. Seeds. Human labor, animal labor, machine labor, chemical fertilizers, manures, pesticides and irrigation facilities are some of the important inputs that determine the yield. Profitability depends on the efficiency with which farmers are able to utilize these resources (Watkins et al., 2014; Wali et al., 2019; Konja et al., 2019). The study aimed to examine the productivity and profitability of Bt and non-Bt farmers in Tamil Nadu and Maharashtra. Additionally, the study investigated how best the farmers used their resources to bring the maximum yield.

MATERIALS AND METHODS

The present study is based on information collected from published sources. Data on cotton crop harvest area, production, and yield for the entire state were scanned from several issues of the Tamil Nadu Statistical Abstract, Seasonal Crop Reports. The cost and return were analysed separately for Bt and non-Bt production in the selected two states using plot-level production information collected from plot-level CCS data (DES, Govt. India). Based on the seed price and quantity, the plots were segregated into Bt and non-Bt cotton crops from both Tamil Nadu and Maharashtra for 2002 and 2017.

Resource use efficiency

To estimate the resource usage efficiency in cotton farming, the production function approach was utilized. The Cobb–Douglas production function was used for this purpose. (Meeusen & van den Broeck, 1977). The input coefficients constituted the corresponding elasticities, which was the single most advantageous feature of this production function. Eq. 1 shows the modified form of the Cobb–Douglas production function.

$$Y= a X_1^{b1} X_2^{b2} X_3^{b3} X_4^{b4} X_5^{b5} X_6^{b6} X_7^{b7} X_8^{b8} X_9^{b9} e \quad \text{... Eq. 1}$$

where,

Y = Main Product per hectare (Qtl/ha)

X_1 = Seed Quantity (kg/ha)

X_2 = Human Labour (Man Days)

X_3 = Animal Labour (Hrs)

X_4 = Machine (Hrs)

X_5 = Nitrogen (kg/ha)

X_6 = Phosphorous (kg/ha)

X_7 = Potassium (kg/ha)

X_8 = Farm Yard Manure (FYM) (Qtl/ha)

X_9 = Irrigation Machine (Hrs)
e = Random-error
After converting it to loglinear form, the Cobb–Douglas function was evaluated using the ordinary least square (OLS) method. (Hamsa et al., 2017; Konja et al., 2019). The equation's estimable form (Eq. 2) is presented below.

$\ln Y = \ln a + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 + b_4 \ln X_4 + b_5 \ln X_5 + b_6 \ln X_6 + b_7 \ln X_7 + b_8 \ln X_8 + b_9 \ln X_9 + e$ ….Eq. (2)

The economic efficiency of the resources used was determined by using the MVP and MFC ratio. The MVP and its ratio (r) with MFC were calculated using the estimated coefficients. The model used for estimation of r (Eq. 3) was as follows:

$R = MVP/MFC$ ….Eq. (3)

where r = efficiency ratio; MVP = marginal value product of variable inputs; MFC = marginal factor cost (price of inputs)

According to economic theory, when the marginal return-to-opportunity cost ratio is one, the farm maximizes profitability in terms of resource utilization. The values are interpreted thus; $r > 1$ indicates underutilization, $r < 1$ indicates overutilization, and if $r = 1$, the resource is optimally used and hence is the point of profit maximization.

Technical efficiency

The technical efficiency of the farm assessed its ability to produce the most potential output from a given set of resources. Technical and allocative efficiencies were not distinguished by the Cobb–Douglas production function. It ignored the issue of technical efficiency by assuming that all farming techniques were the same and that every farmer was technically efficient, which was rarely the case. Farrel (1957) established the concept of the frontier production function, which distinguished between technical and allocative efficiencies. (Farrell, 1957). Some authors put the concept into practice by imposing the Cobb–Douglas type on the frontier and developing an output-based efficiency metric (Timmer, 1971; Prathap, 2017; Seema Shaktawat, et al., 2012; Shanmugam and Venkataramani, 2006). The statistical analysis was approached by specifying a stochastic frontier production function. This takes a general form as (Eq. 4):

$Y = f(X where X)\, e^{(\mu)}$ ….Eq. (4)

where,
Y = Output (dependent variable);
X = Inputs (independent variables);
μ = Error-term.
This function in loglinear form (Eq. 5) would be:

$\ln Y = \ln a + \sum b_i \ln X_i + \mu$ …..Eq. (5)

RESULTS AND DISCUSSION

Bacillus thuringiensis (Bt) is a naturally occurring soil bacterium that produces a protein that is toxic to lepidopteran insect pests. Cotton has been genetically modified to contain the Bt bacterium gene, making it insect resistant. A transgenic crop that is insect-resistant and resistant to the bollworm. According to Choudhary and Laroia (2001), bollworm infestation must be addressed in the early phases of plant growth (Choudhary and Laroia, 2001). Bt cotton has been shown to be effective against bollworms and has decreased the use of insecticides. As a result, an environmentally friendly atmosphere has been created while maintaining a viable output. (Rocha-Munive et al., 2018; Manickam et al., 2008; Sadashivappa and Qaim, 2009). In addition to reduced production costs and increasing profit, Bt cotton has reduced farming risk and improved farmers' perspectives on cultivating cotton crops. (Singh, 2018; Kranthi and Stone, 2020)

After the approval of commercial production of Bt cotton in India during 2002, there was an increase in the area under Bt cotton. As a result of Bt cotton introduction, the yield was almost doubled (Fig. 1) of good-quality cotton fibre with less input use, specifically insecticides (Gandhi, 2009). From Table 1, the average yield of both Bt and non-Bt cotton was found to be high in Tamil Nadu, as the state tops productivity in India (Ministry of Textiles, 2017). There is a need to increase the efficiency of Maharashtra farmers to harvest more yield in both Bt and non-Bt cotton.

Descriptive analysis

Table 2 presents the summary of the variables used in the study. On average, each cotton farm in Tamil Nadu and Maharashtra produced 10.7 quintal and 7.92 quintal cotton during 2002, i.e., non-Bt cotton using seed quantities of 5.09 kg and 2.90 kg, respectively. It also shows that the use of chemical fertilizers has increased over the years and that the usage of farmyard manure is showing a decreasing trend. Animal labour has been

Table 1. Average yield of cotton in Tamil Nadu and Maharashtra

Variable	Tamil Nadu			Maharashtra		
	2002	2017 Non-Bt	2017 Bt	2002	2017 Non-Bt	2017 Bt
Sample Size	22	27	68	339	103	248
Yield	11.52	13.70	22.73	9.05	9.64	16.60

Source: DES. GoI. India (2002 & 2017)

decreasing over the years due to steady usage of human labour and machine labour along with the decreased animal population.

From Table 3, on average, per hectare farm requires 5 kg of seed in non-Bt cotton in Tamil Nadu during 2002, whereas as in Maharashtra, it requires 3 kg of non-Bt cotton seeds. With the average gross margin of Rs. 110797 per hectare in Tamil Nadu, the average seed rate is 2 kg and for Maharashtra the same quantity of seed was used, the return was Rs. 63996 per hectare. The recommendation of Bt cotton seed per hectare is 2 kg per hectare.(Srikanth Reddy et al., 2020).

In Tamil Nadu, the total cost of cultivation (Cost C_3) was Rs. 37330 per hectare during 2002, Rs. 100924 per hectare in the non-Bt cotton category in 2017 and Rs. 139365 per hectare in Bt cotton category in 2017. Similar results were obtained by) who reported that production of Bt cotton would be more profitable if resources weree used more efficiently, which would have a considerable impact on returns for Bt cotton farm households Warangal district of Telangana state. In Maharashtra, the net returns from cotton in 2002 were Rs.23289 per hectare and Rs.90721 per hectare in the non-Bt cotton category in 2017 and Rs. 91018 per hectare in Bt cotton during 2017. Fig. 2 reveals that the per hectare net return of both Bt and non-Bt cotton was higher in Tamil Nadu than in Maharashtra during 2002 and 2017. Increasing net returns can be attributed to higher yields and farmers' ability to keep produce for longer periods of time, which enabled them get a better price and higher returns per quintal (Kumar et al., 2021).

Resource use efficiency

Table 4 shows the resource use efficiency of Bt cotton and non-Bt cotton using the Cobb Douglas production function. In this study, cotton farmers' resource usage efficiency was determined by the ratio of the MVP of each input utilized to their respective factor prices. The largest contributor to the total productivity differential between Bt and non-Bt cotton was identified as technology. The cost of seeds, the yield of Bt cotton, and the cost of plant protection have all been shown to have a significant impact on the likelihood of Bt cotton adoption. The most significant barriers to Bt technology deployment have been recognized as a lack of high-quality seeds in sufficient quantities. Farmers have reported higher production, reduced insect and disease incidence, increased income, employment, education, and level of living, and reduced health risk as a result of Bt cotton cultivation.

The overall resource use efficiency is given in Table 5. The seed was overused during 2002 in both Tamil Nadu and Maharashtra. Human labor was under use in Maharashtra during the entire period. In Maharashtra, animal labour, machine labour and irrigation machines are overutilized, while human labour is underutilized, which indicates a dependency on farm machinery (Kumar et al., 2021). Farm mechanization plays a major role in labour input and shows a negative impact on labour absorption (Raut, 2015). In Tamil Nadu, nitrogen was underutilized by non-Bt cotton farmers during 2017, as the recommended usage of nitrogen was approximately 100 kg/ha. Animal labour was underutilized by non-Bt cotton farmers in Tamil Nadu during 2017. All other variables were not unexplained due to nonsignificance.

Technical efficiency

The farm size-based technical efficiency of Bt cotton

Table 2. Summary statistics of the variables used in the study

Variables	Tamil Nadu			Maharashtra		
	2002	2017 Non-Bt	2017 Bt	2002	2017 Non-Bt	2017 Bt
No. of Sample	22	24	71	339	25	326
Yield (Qtl/ha)	11.52	13.70	22.73	9.05	9.64	16.60
Seed (kg/ha)	5.09	14.82	2.19	2.90	1.73	1.71
Human Labour (MD)	176.05	137.15	156.21	107.93	104.42	112.28
Animal Labour (Hrs)	49.53	.	14.42	124.59	52.87	58.26
Machine (Hrs)	17.21	12.91	15.20	9.12	19.51	13.93
Nitrogen (kg/ha)	53.00	61.25	113.12	56.61	55.35	93.47
Phosphorus (kg/ha)	36.85	35.13	49.73	34.32	99.92	73.91
Potassium (kg/ha)	38.99	41.19	68.42	17.38	58.66	49.17
FYM (Qtl/ha)	120.95	21.05	29.61	40.07	.	17.12
Irrigation Machine (Hrs)	269.15	171.06	203.22	59.70	108.30	62.35

Source: DES. GoI. India (2002 & 2017)

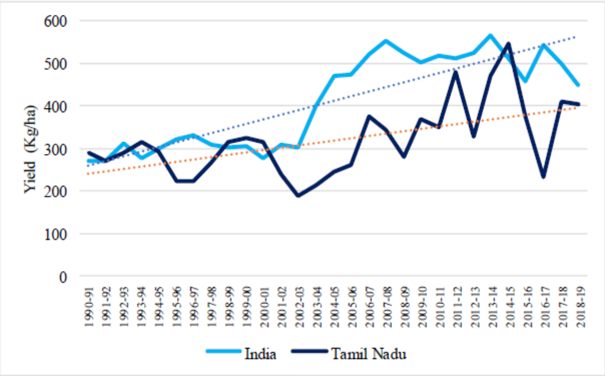

Fig. 1. *Cotton yield per hectare in Tamil Nadu and India (1990-2019)*

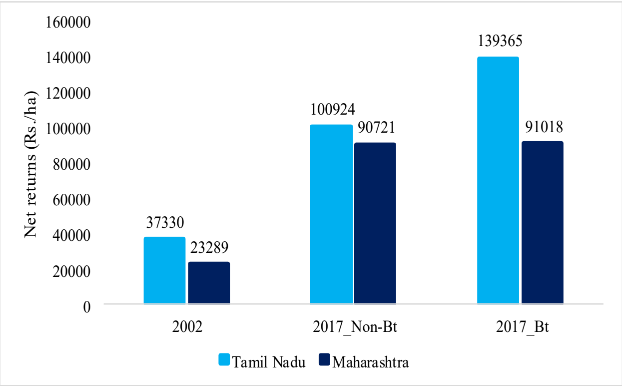

Fig. 2. *Net returns from cotton (Rs./ha)*

Table 3. Cost and returns from Bt and Non-Bt cotton in Tamil Nadu and Maharashtra, 2002 & 2017

Variables	Tamil Nadu			Maharashtra		
	2002	2017 Non-Bt	2017 Bt	2002	2017 Non-Bt	2017 Bt
No. of Sample	22	24	71	339	25	326
Gross Margin_ha (Rs.)	23643	56671	110797	18298	80121	63996
Seed_ha (kg.)	5	14	2	3	2	2
Seed Price (Rs.)	359	1200	1886	566	1749	1775
Cost A1_ha (Rs.)	19365	48428	81620	16456	62619	60430
Cost A2_ha (Rs.)	19509	48428	81620	16456	62619	60430
Cost B1_ha (Rs.)	19365	48448	81640	16456	62633	60448
Cost B2_ha (Rs.)	24863	57427	102262	19506	75989	71116
Cost C1_ha (Rs.)	28437	82770	106074	18121	69118	72075
Cost C2_ha (Rs.)	33936	91749	126696	21171	82474	82743
Cost C3_ha (Rs.)	37330	100924	139365	23289	90721	91018

Source: DES. GoI. India (2002 & 2017)

Table 4. Estimation of the Cobb–Douglas production function for Bt and Non-Bt cotton in Tamil Nadu and Maharashtra

Variable	Tamil Nadu			Maharashtra		
	2002	2017 Non-Bt	2017 Bt	2002	2017 Non-Bt	2017 Bt
No. of Sample	22	24	71	339	25	326
Constant	0.612	2.161	1.870	0.324	1.178	-0.684
Seed (kg/ha)	-0.194*	-0.509	0.118	-0.198***	0.150	-0.086
Human Labour (MD)	0.331	0.391	0.211	0.401***	0.802**	0.622***
Animal Labour (Hrs)	0.016	0.000	0.217*	-0.052	-0.363**	-0.011
Machine (Hrs)	0.006	-0.193	-0.072	0.059**	-0.358*	0.015
Nitrogen (kg/ha)	0.205	0.743*	0.075	0.049*	-0.296*	0.028
Phosphorus (kg/ha)	-0.168	-0.390	0.119*	-0.014	0.314	0.031
Potassium (kg/ha)	-0.021	-0.367	-0.121	0.008	0.116**	0.041***
FYM (Qtl/ha)	-0.023	0.138	-0.025	-0.011	0.000	-0.014
Irrigation Machine (Hrs)	0.075	-0.015	-0.004	0.098***	-0.212***	-0.004
Yield (Q/ha)	10.736	13.171	21.098	7.92	14.426	13.252
R2	0.91	0.55	0.28	0.54	0.89	0.31
Adjusted R2	0.85	0.31	0.17	0.52	0.83	0.30
F-ratio	13.92	2.30	2.63	42.36	16.36	16.11

Note: ***, ** and * indicate coefficients that are significant at 1, 5 and 10 %, respectively. (Source: DES. GoI. India (2002 & 2017) production is presented in Table 6. Table shows that in Tamil Nadu, 41 % of farmers were in the more efficient category (>90), and 59 % of farmers were in the 60-90 category during 2002. In Tamil Nadu, 28 % of farmers were in the more efficient category (>90), 48 % of farmers were in the 60-90 % category, and 24 % fell under the less efficient category (<60). From the table, during 2002, 8 % of farmers were in the more efficient category (>90), 58 % of farmers were in the 60-90 category and 34 % of farmers were in the less efficient category (<60) in Maharashtra. Ninety % of Bt cotton farmers fell under the 60-90 efficient category in Maharashtra during 2017. Similar results were obtained by Mal et al. (2011), who stated that the technical efficiency of Bt cotton farming was higher in the states of Punjab and Haryana, i.e. 80 % of Bt cotton farms fall in the higher efficiency category of 80-90 % efficiency. Frontier efficiency analysis clearly indicated a reduction in mean technical efficiency (MTE) in the case of Bt cotton due to a lack of adoption of the practices required to adopt Bt cotton; hence, training may be given to reduce inefficiency in both states.

Farm sizewise MTE analyses for Bt cotton farms in 2017 are represented in Fig. 3. The results indicated

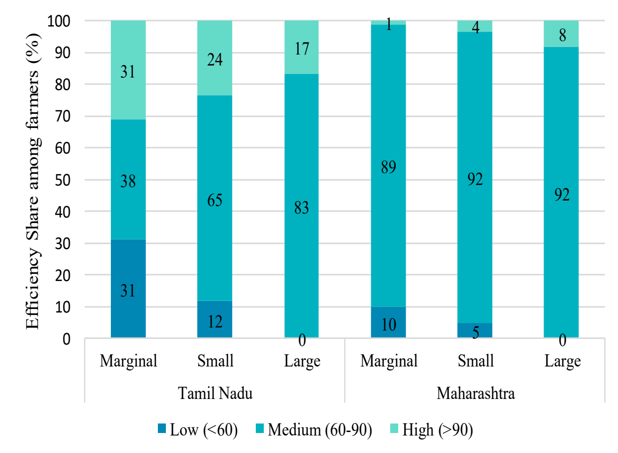

Fig. 3. *Mean technical efficiency share among Bt cotton farmers of Tamil Nadu & Maharashtra, 2017*

that most marginal and small farmers were still in the low efficiency category, indicating further scope to increase the efficiency in the target farms by technology training and the distribution of quality Bt seeds at the subsidised rate to the marginal small farmers. Farms with less efficiency than 60 % obtained lower yields than highly efficient farms. The gap between the highly

Table 5. Overall resource use efficiency of Bt and Non-Bt cotton in Tamil Nadu and Maharashtra during 2002 & 2017.

Variable	Tamil Nadu			Maharashtra		
	2002	2017 Non-Bt	2017 Bt	2002	2017 Non-Bt	2017 Bt
Seed (kg/ha)	Over	-	-	Over	-	-
Human Labour (MD)	-	-	-	Under	Under	Under
Animal Labour (Hrs)	-	-	Under	-	Over	-
Machine (Hrs)	-	-	-	Under	Over	-
Nitrogen (kg/ha)	-	Under	-	Under	Over	-
Phosphorus (kg/ha)	-	-	Under	-	-	-
Potassium (kg/ha)	-	-	-	-	Under	-
FYM (Qtl/ha)	-	-	-	-	-	-
Irrigation Machine (Hrs)	-	-	-	Under	Over	-

Source: DES. GoI. India (2002 & 2017)

Table 6. Technical efficiency of Bt and Non-Bt cotton in Tamil Nadu and Maharashtra during 2002 & 2017.

Efficiency categories (%)	Tamil Nadu			Maharashtra		
	2002	2017 Non-Bt	2017 Bt	2002	2017 Non-Bt	2017 Bt
< 60	-	-	17(24)	115(34)	4(16)	27(8)
60 – 90	13(59)	-	34(48)	196(58)	11(44)	292(90)
> 90	9(41)	24(100)	20(28)	28(8)	10(40)	7(2)
Total farmers	22(100)	24(100)	71(100)	339(100)	25(100)	336(100)
Mean TE	99.6	94.2	76.2	71.90	97.3	79.06

Figures in parentheses indicate %age of farmers; Source: DES. GoI. India (2002 & 2017) efficient and less efficient farms is too large in the case of Maharashtra and needs to be examined.

The efficiency of two-thirds of farmers was found to be greater than 60% in a frontier production function study, indicating that cotton output may be boosted by improving the technical efficiency of less efficient farms through appropriate extension services delivery. Furthermore, there is scope in increasing technical efficiency with a given resource use level. Hence, more knowledge on Bt cotton technology may be given to farmers by means of training/educating/capacity building.

Conclusion

The Cobb–Douglas production function was used to estimate the resource-use efficiency of cotton production, and the technical efficiency was calculated using the stochastic frontier production function. Most of the resources are not optimally utilized, and there is a need for reallocation of the resources, as the MVP to MFC ratio was negative and more than one for most of the inputs. Farmers have been trained and well equipped with technical efficiency through extension efforts of Krishi Vigyan Kendra (KVK's), State Agricultural Universities (SAU's) and Indian Council of Agricultural Research (ICAR). This component needs to be further strengthened by educating/training/capacity building of farmers with regard to allocative efficiency by comparing the marginal productivity of each resource with the relative price ratio of input to output. In particular, this is required for the use of inputs such as human labour, animal labour and fertilizer (NPK). The efficiency of two -thirds of farmers was found to be greater than 60% in a frontier production function study, indicating that cotton output may be boosted by improving the technical efficiency of less efficient farms through appropriate extension services delivery. Farmers were still underusing Bt cotton seeds due to the costs of the seeds. Hence, efforts may be made to regulate Bt cotton seed prices. Furthermore, there is scope for increasing technical efficiency with a given resource use level. Hence, more knowledge on Bt cotton technology may be given to farmers by means of training/educating/capacity building.

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Conflict of interest

The authors declare that they have no conflict of interest.

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