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Measuring efficiency of cotton production in Haryana: Application of data envelopment analysis

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ABSTRACT: Haryana ranks second after Gujarat in production of cotton among irrigated states of India. The present study provides the sources of inefficiency of cotton farmers in Palwal district of Haryana. The non parametric approach, Data Envelopment Analysis, has been used to determine efficiencies (technical, allocative, scale and cost) of cotton farmers having similar conditions like soil types, cropping system, agro environment and access to markets. In the 'cotton-wheat' system of study area, there is a scope to improve efficiency of individual farm (especially allocative and cost efficiencies) growing cotton. Results show that mean efficiency scores for technical, scale, allocative, scale and cost were 97.3, 93.7, 87.6 and 85.2 per cents, respectively. Efficiency scores imply that cotton farmers were technically efficient, but there is a scope in improving their allocative and cost efficiencies by 12 and 15 per cent, respectively, thereby making cotton cultivation cost effective and profitable. Analysis revealed that by reassembling of resources, about 20 per cent of operational cost could be reduced without affecting the yield level. However, results emerged from small sample farms data need great care in interpreting the findings for any policy decision.

Key words: Cobb-douglas production model, cotton, data envelopment analysis, efficiency

Cotton (*Gossypium* spp) is the key fibre producing crop in India. It is grown in about 12 million ha of area with annual production of 32.3 million bales during triennium ending (TE) 2016-2017. During 2016-2017, India produced raw cotton worth ' 69,639 crores (2011-2012 prices) which accounted for 94 per cent of total value generated from fibre crops (MoSPI, 2018). In the global scenario, India ranks first in both area and production of cotton and contributed 36.7 and 22.1 per cent, respectively, during 2016-2017. Though, India is self-sufficient in cotton output and having net trade over past one decade (500 thousand tonnes during 2016-2017), however there is a mismatch in quality wise demand. Also, the average yield of cotton in India is 465.3 kg/ha in terms of lint and lower (39%) than the global average (758 kg/ha). Several reasons are attributed to low yield including weather aberrations, inadequate/ excess rains and its uneven distribution, cultivation in uplands (shallow/ light soils), incidence of pests especially sucking pests, and wilting in *Bt* cotton hybrids (MoAFW, 2017). Cotton is grown in both rainfed[1] (sharing 60 per cent of area and 50 per cent output) and irrigated condition in India. The difference in yields among cotton states is obvious and this knowledge helps to bridge the gap. The difference in yields refers to yield gap which arises due to inefficiency (technical, allocative or both) in cotton cultivation.

A number of studies on technical and allocative efficiencies of crop production, particularly cereals (rice and wheat) have pointed out existence of yield gap. This refers to difference in productivity on best practices and on other farms operating with similar resource endowments. Efficiency in cotton production in northern India where cotton is grown in irrigated condition is less reported. The past studies on efficiency (technical and economic) have used parametric methods to assess 'average' efficiencies only (Ali and Chaudhry, 1990; Battese *et al.*, 1993; Parikh and Shah 1994; Parikh *et al.,* 1995). The concept of 'average' efficiencies actually ignores and limits the idea of studying the individual farms which is important for measuring the resource use efficiency, and that the parametric methodology provides insufficient information for policy analysis (Kalirajan, 1984; Kalirajan and Shand, 1986). In the present study, all the farms have given equal weight, and non-parametric method of data envelopment analysis (DEA) is used to examine the efficiency of cotton growing sample farms in Haryana.

The DEA is a non parametric, linear programming approach for measuring relative efficiency among a set of sample respondents. The result of DEA is expected to answer the extent of possible increase in cotton production by improving technical efficiency. The results of the study are expected to guide the farmers and decision makers so that the farmers can either produce the current level with minimum cost or produce more with the present cost structure which will help to enhance farm income and ultimately improving export to foreign market.

MATERIALS AND METHODS

Study area: The present study was undertaken in adopted villages in Palwal district of Haryana under the scheme *Mera Gaon Mera Gaurav*[2] (My village my pride). The villages include *Jor Khera*, *Rakhota* and *Nagli Pachanki* (in Palwal block) and *Khokiyaka* in Hathin block of the district. The climate of district is semi-arid and hot with moderate temperature round the year. The district receives normal rainfall of about 542 mm during the rainy season (July-September) and dry winds during summer (May-June). The farmers of study villages grow main cash crops of cotton and sugarcane, and food crops like wheat, rice, bajra, etc. Besides, farmers rear milch animals (buffalo) mainly for milk for home consumption.

The sample of cotton producers: Two stage sampling technique has been adopted in the study. The first stage was purposive selection of adopted villages from Palwal district, and in second stage random selection of farmers was done. Thirty farmers from each village were selected making a total of 120 farmers who followed cotton wheat system on their farms. The households were post stratified into small, medium and large size categories on the basis of operational land holdings. Farmers having land less than 2 ha were classified as small; while farmers having 2-4 ha were grouped as medium and farmers having above 4 ha were classified as large farms. Thus, sample of 120 farms contained 50 small, 40 medium and 30 large farms.

The selected farms are homogenous group for several reasons. First, all the farmers of study area follow almost the similar cropping practices. Second, they are in reasonable proximity to each other. Third, all of them are facing uniform natural and market conditions and have same infrastructure. Finally, all the farms have broadly similar types of soils.

Data description: The data were collected from sample households growing cotton a major crop including bajra in *kharif* season (wheat and rapeseed and mustard in *rabi* season). The inputs used in cotton cultivation include seed, chemical fertilizers, labour (both family and hired labours), irrigation, insecticides and zinc, etc. The socio economic features of farmers and farms include farmer's age, his education, the family size and number of family members working on farm, landholding size and cattle population etc. The data utilized for the analysis related to agricultural year 2017-2018.

Measurement of production efficiency: The measurement of efficiency begins with the work of Farrell (1957). Farrell introduced the concept of relative efficiency in which the efficiency of a particular production unit may be compared with another production unit within a given group. He identified three types of efficiency, technical, allocative (referred to by Farrell as "price efficiency"), and economic efficiency (referred to by Farrell as "overall efficiency"). Technical efficiency refers to the ability of a farm/firm to produce the maximum feasible output using a given bundle of inputs. Allocative efficiency (an economic concept) on the other hand refers to how different resource inputs are combined to produce a mix of different outputs. Economic efficiency, also known as cost efficiency, is the product of both technical efficiency and allocative efficiency and measurement of scale efficiency provides the ability of the management to choose the optimum size of resources. Thus, a farm is economically efficient if it is both technically and allocatively efficient.

Building on Farrel's work, Charnes *et al.,* (1978) originally developed the fractional linear programming method of DEA. A comprehensive description of DEA methods is provided by Coelli *et al.,* (1998). The DEA model named after its originators and is called as the CCR model. It optimizes a scoring function defined as the ratio of weighted sum of outputs of an individual production unit and the weighted sum of its inputs used, called efficiency. The model optimizes subject to the condition that with any of the production units in the model, the value of objective function achieved cannot be more than 1, implying that efficient units will have a score of 1. The DEA model is regarded as one of the popular techniques of efficiency analysis. The input-oriented DEA model used for estimation of technical efficiency by Coelli (1996) is :

Min $_{è\,ë}$ è,

Subject to

$- q_i + Q\,ë$ e" 0

$è r_i - Rë$ e" 0 (1)

N 1'ë = 1

ë e" 0,

where è is a scalar and subscript i stands for the i-th farm, N1 is an N×1 vector of constant and N1'ë is a convexity constraint. The acquired value of è is the technical efficiency score for the i-th farm where the TE score having a value varying from 0 to 1; ë is an N×1 vector of constants (weights) that delineates the linear combination of the peers of the i-th farm; Q is a vector of output quantities and R is a vector of observed inputs. A score of 1 entails that the farm is on the frontier and it is fully efficient.

RESULTS AND DISCUSSION

General characteristics of farmers and farms: The data on features of sample households such as farmer's age, education, family size and family members engaged in farming is presented in Table 1. Results show that about two-third of the farmers were over 40 years of age and nearly 26 per cent were in the age group of 31-40 years. The family size was large as one third families had more than nine members and 47 per cent farmers had between 5 and 8 members. Data shows that about half of the farm families had 4 or more full time family labour working in farms. About education, 63 per cent of farm households had at least primary education and up to eighth level and another 20 per cent were having education of 10th standard and above.

About two fifth of households (42%) had small size holding (less than 2 ha), and another one-third (33.3%) had medium size farms (2-4 ha). Most of the farmers cultivate their own land, but more than one-fourth took on lease (27%) along with owned land to increase the operational size of their holdings (Table 2). All the farms have similar types of soils (shallow and light texture) not very ideal for growing cotton, as black soil is preferred for cotton cultivation. Small households devoted more than three-fourth of cultivated land to cotton crop, while medium and large size farms allocated about 60 per cent of their cultivated area under cotton.

Role of inputs in crop productivity: A large number of studies have usually combined some form of functional analysis with the DEA model, mostly regression model, to identify inputs that play a prominent role in determining productivity. Subsequently, the relative efficiency of a production unit can be measured (Charnes *et al.,* 1978; Bowlin *et al.,* 1985; Dyson *et al.,* 1990; Roll and Cook, 1993; Thanassoulis, 1993). Thus, a Cobb-Douglas type of production

Table 1. Characteristics of sample farm households

S. No.	Characteristics of farmers	Frequency	Per cent
1	**Age of the head of farm households**		
	Less than 30 years	8	6.7
	30-40	31	25.8
	41-50	46	38.3
	Above 50 years	35	29.2
2	**Family size (number)**		
	1-4	29	24.2
	5-8	56	46.7
	9-12	25	20.8
	Above 12	10	8.3
3	**Family members involved in full time farming (number)**		
	1	9	7.5
	2	45	37.5
	3	5	4.2
	4 or more	61	50.8
4	**Education attained**		
	No schooling	2	1.7
	Up to 5 years	17	14.2
	5-10 years	76	63.3
	10-12 years	21	17.5
	Above 12 years	4	3.3

Source: Authors' estimate;

function was fitted to the data collected from cotton households through personal interview method and the results are provided below.

Description of the variables: The main inputs considered to determine the cotton yield (kg/ha) include nitrogenous and phosphatic fertilizers (nutrient kg/ac), labour (days/ac), irrigation cost ('/ac), insecticides cost ('/ac), and machine cost for field operations ('/ac). The basic statistics related to these variables are given in Table 3. It is clear that there is a wide variation in both the inputs used and cotton output. The output obtained by some of the farm households was almost double of others; and there were wide variations in the levels at which inputs were being used. There were large differences in use of insecticides as some farmers were incurring ten times more expenses on insecticides, while difference in use of nitrogen and phosphatic fertilizers were double of others. For cotton growing, some farmers did few ploughing, while some did more ploughing and incurred 1.5 times more cost of others. Such a variation in levels of inputs used implied that possibly there is mis-utilization of resources.

Estimates of production function model: The regression coefficient obtained from C-D production function is presented in Table 4. The value of adjusted R^2 (0.548) shows that the model is able to explain a great deal of the relationship between the dependent and independent variables as most of the variables had expected sign and significantly influence the increase in cotton yield. Variables like human labour use, application of phosphatic fertilizer and expenditure on machine use and zinc had shown positive and significant effect on yield, implying further increase in use of these resources to achieve higher yield. However, resources like nitrogenous fertilizer use,

Table 2. Characteristics of sample farm households

S. No.	*Characteristics of farms*	Number	Area (ac)
1	**Farm size**		
	Small (< 2 ha)	50 (41.7)	2.44
	Medium (2-4 ha)	40 (33.3)	6.24
	Large (Above 4 ha)	30 (25.0)	16.62
2	**Type of tenancy on farm**		
	Owned	86 (71.7)	71.7
	Rented	2 (1.7)	1.7
	Owned plus rented	32 (26.7)	26.7
3	**Area under cotton in different farm size categories**		
	Small (< 2 ha)	50 (41.7)	1.87
	Medium (2-4 ha)	40 (33.3)	3.65
	Large (Above 4 ha)	30 (25.0)	10.58
4	**Share of cotton crop on different farm size categories (%)**		
	Small (< 2 ha)	50 (41.7)	76.64
	Medium (2-4 ha)	40 (33.3)	59.60
	Large (Above 4 ha)	30 (25.0)	63.50

Source: Authors' estimate; *Note*: Figures in parentheses are per cent to total.

Table 3. Basic statistics of cotton output and inputs used

Output / input variables	Minimum	Maximum	**Mean**	S.D.
Cotton yield (q/ac)	5.5	9.0	**7.32**	0.734
Inputs				
Nitrogenous fertilizer (kg nutrient/ac)	23.74	44.36	**32.80**	3.367
Phosphatic fertilizer (kg nutrient/ac)	9.20	20.37	**16.56**	3.10
Human labour use (days/ac)	32	50	**41.51**	4.166
Irrigation cost (‘/ ac)	1120	2800	**2318.45**	358.48
Insecticide cost (‘/ ac)	200	2100	**755.71**	307.371
Machinery cost (‘/ ac)	1440	2400	**2058.48**	242.010

expenditure on insecticides and irrigation showed negative returns, implying excessive use of these inputs. Thus, the levels at which these inputs are being used could be lowered without reduction in yield level. These results in effect confirm the need for undertaking analysis of the efficiency of production using a non parametric method like DEA, as identifying inefficient farms would imply discovering the extent by which their input use could be improved. Moreover, when there is a large variation in inputs used and the yield achieved as presented in Table 3, the efficiency analysis of individual farms assumes greater significance.

Technical, allocative, cost and scale efficiency analysis: The frequency distribution of farms according to levels of efficiency and coefficients of technical, allocative, cost and scale efficiencies are given in Table 5. Crop sector usually follows the law of variable proportions and is dissimilar with industry. In this study, input oriented model was applied because the input is the key factor for farmers as buying inputs is constrained due to financial problem with many small farmers. Therefore, justification for applying input oriented model to determine efficiencies thus appear appropriate; Gul *et al.,* (2009) also made use of an input-oriented variable return to scale (VRS) DEA model to estimate efficiency of cotton

Table 4. Production coefficients estimated from the Cobb-Douglas cotton production function

Variables	Coefficients(âi)	Standard error	Significance
Constant	- 1.126	0.528	0.035
Human labour (days)	0.641	0.066	0.000
Phosphorus (kg)	0.206	0.038	0.000
Machine labour cost (Rs)	0.110	0.053	0.041
Zinc cost (Rs)	0.003	0.001	0.05
Nitrogen (kg)	-0.150	0.078	0.058
Pesticides cost (Rs)	-0.028	0.016	0.083
Irrigation cost (Rs)	-0.001	0.035	0.980
F statistics	df (7,112) 21.647 (Sig 0.000)		
R square	0.575		
Adjusted R^2	0.548		
Durbin Watson statistics	1.938		

Source: Authors’ estimate

farmers of Turkey.

The efficiency scores for all the farms reported in table 5 showed that, when VRS are assumed, 91.7 per cent farms (110 farms) were operating with technical efficiency level of 100 per cent, and remaining 8 per cent (10 farms) had efficiency scores between 90 and 100 per cent. Whereas, when CRS are assumed, 61 per cent of farms (73 farms) had efficiency scores of 100 per cent and another 30 per cent (36 farms) were operating between 90 and 100 per cent. It was noted that only one farm has efficiency level below 70 per cent. The mean technical efficiency for cotton under VRS model was 0.973. This suggests that average farms were producing output with 97 per cent potential level. This also suggests that there was only 3 per cent managerial inefficiency and 6 per cent scale inefficiency.

The analysis of allocative efficiency depends on assumptions made about a farmer's behaviour. Farrel (1957) assumed that farmers' allocate resources on the basis of cost minimization to obtain a given level of output. Allocative inefficiency is a famer's inability to equate the ratio of marginal products to the ratio of their respective prices. Lau and Yotopoulos (1971), Schmidt and Lovell (1979), and Kopp and Diewert (1982) had assumed profit maximization approach and defined allocative inefficiency as the failure to equate the marginal value product of inputs to their prices. In the DEA model, however, the behavioural assumption is more sensitive as the allocative efficiency is the proportion by which the costs of the levels of inputs on a farm can be reduced without any loss in output.

To analyse allocative efficiency of cotton farms, the costs of individual inputs used have been estimated by using the actual prices paid by the farmers. The input variables were pooled together to reduce the number of cost variables to facilitate the analysis. The variables included were cost (in ‘ per acre) on (i) land preparation, (ii) cotton seed, (iii) fertilizer, (iv) irrigation, (v) insecticides usage, etc. The results given in table 5 show that, assuming VRS, more than half (64 farms) of cotton farms were operating between 90 and 100 per cent efficiency levels,

Table 5. Frequency distribution of technical, scale, allocative and cost efficiency

Efficiency level (%)	TE_{CRS}		TE_{VRS}		SE		AE		CE	
	No. of farms	Total farms (%)	No. of farms	Total farms (%)	No. of farms	Total farms (%)	No. of farms	Total farms (%)	No. of farms	Total farms (%)
1.00	73	60.80	110	91.67	31	25.83	43	35.83	28	23.33
0.90 <1.00	36	30.00	10	8.33	57	47.50	64	53.33	64	56.67
0.80< 0.90	10	8.33	0	0	29	24.17	13	10.83	24	20.00
0.70< 0.80	1	0.83	0	0	3	2.50	0	0	0	0
Mean		0.912		0.973		0.937		0.876		0.852
Std. dev		0.0774		0.0421		0.061		0.0586		0.0657
Minimum		0.671		0.837		0.760		0.734		0.710
Maximum		1.000		1.000		1.000		1.000		1.00

Note: TE=Technical Efficiency; SE=Scale Efficiency; AE=Allocative Efficiency; CE=Cost Efficiency

Source: Authors' estimate

and other 36 per cent (43 farms) were operating with 100 per cent efficiency level. Whereas, assuming constant return to scale (CRS), nearly 21.7 per cent farms had efficiency scores of 100 per cent, and another 46.7 per cent were having efficiency scores between 90 and 100.

The estimates of mean scale efficiency (SE) 0.937 indicate that farms are scale efficient. This implies that there was about 6 per cent scale inefficiency. The scores of SE describe the ability of farm to choose the optimum level of resources. However, 74 per cent farm growing cotton (89 farms) had scale efficiency level below 90 per cent. The distribution of scale efficiency is skewed towards right and reflects that about three-fourth farms had efficiency in the distribution level of 0.9 to 1.

CONCLUSIONS

The present study was aimed to work out technical, allocative, scale and cost efficiencies of cotton farmers in Haryana and to explain variations in efficiency levels among farms. The farm specific efficiency scores were computed using 2017-2018 cotton production data collected through personal interview from farmers of villages adopted under MGMG scheme in Palwal district. An input oriented DEA approach was used to generate efficiency coefficients. Data shows that mean technical, allocative, scale and cost efficiencies were 97, 87.6, 93.7 and 85.2 per cent, respectively. Efficiency scores imply cotton farms are technically efficient, but there is a scope of improving their allocative and cost efficiency levels, by 12 and 15 per cent, respectively. There is also a scope to increase yield level by increasing use of inputs like labour, phosphatic fertilizer, use of zinc and machine. However, excessive use of insecticides, nitrogenous fertilizer and irrigation water need to be reduced to further improve the efficiencies of cotton farms. Thus, cotton growers of study area must be educated about the implications of inputs being used in cotton production. Cotton farmers of the area should also be made aware of fertilizer use as per soil test separately to improve fertilizers/ nutrients effectiveness. Education and awareness can play a major role to convince farmers regardless of farm size and social setting for soil testing and follow recommendations.

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