Plant Archives Vol. 26, No. 1, 2026 pp. 931-936 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.1.126

AN ECONOMIC ANALYSIS OF RESOURCE USE EFFICIENCY IN COTTON CULTIVATION AMONG ADOPTERS AND NON-ADOPTERS OF CLIMATE CHANGE ADAPTATION STRATEGIES IN PALNADU DISTRICT, ANDHRA PRADESH INDIA

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(Date of Receiving-11-01-2026; Date of Revision-02-03-2026; Date of Acceptance-19-03-2026)

ABSTRACT

Climate change is significantly affecting agriculture in India through rising temperatures, erratic monsoons and frequent droughts. Rainfed farming systems are particularly vulnerable due to their complete dependence on rainfall. Cotton, a major rainfed crop, is highly sensitive to moisture stress and temperature fluctuations, leading to reduced yields and increased pest incidence. This threatens the livelihoods of small and marginal farmers who depend on cotton cultivation. These challenges can be addressed through the efficient use of resources by farmers. Hence, a study was made to estimate the resource use efficiency of cotton in the semi-arid Palnadu district of Andhra Pradesh using Data Envelopment Analysis. A total of 180 cotton farmers including 60 adopters and 120 non-adopters across six villages in three major cotton-growing mandals were surveyed for the agricultural year 2023-24. The results revealed that mean technical, allocative and economic efficiencies were found to be 0.926, 0.890 and 0.828 and 0.907, 0.715 and 0.650 for the adopters and non-adopters, respectively. These results confirm that the adopter farmers are economically efficient and the farmers on an average could reduce their cost by 17.20 per cent to produce same amount of output compared to non-adopters by 35.10 per cent. The large gap between TE, AE and EEs of the non-adopter farmers indicates that there is a large scope for increasing the net income of the cotton farmers. The study emphasized that the large gap between TE, AE and EEs of the non-adopter farmers indicates that there is a large scope for increasing the net income of the cotton farmers.

Key words: Climate change, cotton crop, adopters, non-adopters, resource use efficiency, DEA.

Introduction

Climate change has emerged as one of the most significant challenges to global agricultural systems, particularly in tropical and subtropical regions. Agricultural production is inherently climate-sensitive and highly vulnerable to variations in temperature, rainfall patterns and the frequency of extreme weather events (Intergovernmental Panel on Climate Change, 2021). Developing countries such as India are especially at risk due to their large agrarian population, dominance of smallholder farming and heavy reliance on monsoon rainfall (Indian Council of Agricultural Research, 2020).

Cotton, one of India's most important commercial crops, has experienced shifts in productivity, input requirements and profitability under changing climatic conditions. India remains one of the world's leading cotton producers (Food and Agriculture Organization, 2023). In Andhra Pradesh, cotton cultivation is prominent, particularly in semi-arid districts such as Palnadu district. The area under cotton cultivation in Andhra Pradesh has shown a marked decline over the years from 8.21 lakh hectares producing 26.50 lakh bales in 2014–15 to 4.22 lakh hectares yielding 7.37 lakh bales in 2023–24. Productivity has also declined from 570 kg/ha in 2014–

15 to 297 kg/ha in 2023–24. (Season and Crop Reports, 2015–16; 2023–24).

Resource use efficiency defined as the optimal allocation of inputs such as seed, fertilizers, farmyard manure, plant protection chemicals, micronutrients, human labour and machine power to maximize output or profit is fundamental to sustainable agriculture. The theoretical basis for measuring efficiency originates from the neoclassical production function developed by Cobb and Douglas (1928). Later, Farrell (1957) distinguished between technical and allocative efficiency, while stochastic frontier models further refined efficiency estimation (Battese and Coelli, 1995). These frameworks suggest that productivity gains can be achieved through better resource allocation without increasing input quantities.

Climate change adaptation strategies including drought-tolerant varieties, adjustment of sowing dates, micro-irrigation systems, integrated nutrient management and soil moisture conservation are promoted as climate-resilient approaches to enhance productivity and efficiency (Food and Agriculture Organization, 2018). In India, such initiatives are supported under the National Mission for Sustainable Agriculture by the Government of India (2014).

Given the variability in adoption behavior among farmers in Palnadu, a comparative assessment of adopters and non-adopters provides valuable insights into the economic implications of adaptation. This study therefore evaluates whether climate adaptation strategies improve technical and allocative efficiency in cotton cultivation. By applying econometric techniques such as Data Envelopment Analysis, the research aims to identify deviations from optimal resource use and generate policy-relevant evidence for promoting climate-resilient and economically sustainable cotton production systems.

Materials And Methods

The state of Andhra Pradesh was selected for the study due to its significant role in India's cotton production Palnadu district was purposively selected as the specific study location. Formed in 2022, Palnadu holds the second-largest area under cotton cultivation in the state, with 65,347 hectares, 2.04 lakh bales of production, and a productivity of 170 kg/ha in the year 2023-24 (Season and Crop Report, 2023-24).

In Palnadu district three mandals Veldurthi, Amaravathi, and Durgi were purposively selected based on their extensive cotton cultivation during 2023 Kharif season (karshak.ap.gov.in Kharif 2023). From each mandal, two villages with the highest area under cotton were selected. From each village, 30 cotton-growing farmers were randomly selected, including 10 adopters and 20 non adopters of climate change adaptation strategies. Thus, the total sample size comprised 180 farmers.

The data pertaining to the study were obtained through survey method and enquiries were made with the help of pre-tested structured questionnaires. The present study pertains to the agricultural year 2022-23.

Data Envelopment Analysis

Data Envelopment Analysis Data envelopment analysis is a linear programming method for assessing the efficiency and productivity of units called decision-making units. It is a non-parametric approach, first introduced by Charnes *et al.*, (1978). DEA can handle multiple outputs and inputs, as well as single output and multiple inputs or single output and single input. Efficiency can be measured in terms of technical efficiency, allocative or price efficiency and cost efficiency or economic efficiency. Technical efficiency is the ability of the firm to achieve maximum possible output with the given resources, while allocative efficiency refers to the ability to achieve an optimum allocation of given resources. Economic efficiency is a product of technical and allocative efficiencies (Farrell, 1957).

DEA model for estimation of technical efficiency

Suppose there are 'n' homogenous Decision-Making Units (DMUs) and in order to produce 'r' number of outputs (r=1,2,3…. k) 's' number of inputs are utilized (s=1,2,3…m) by each DMU, i (i=1,2,3…n). Assume also that the input and output vectors of ith DMU are represented by xi and yi, respectively and the data for all DMUs be denoted by the input matrix (X) m*n and output matrix (Y) k*n. The DEA model for variable returns to scale (VRS) is developed by Banker *et al.*, (1984). The input minimisation process to measure technical efficiency for each DMU could be expressed as equation:

$$\min_{\theta,\lambda,\phi}$$

$$\text{Subjected to } -y_i + Y\lambda \geq 0,$$

$$\phi x_i - X\lambda \geq 0,$$

$$N_1{}'\lambda = 1$$

$$\lambda \geq 0$$

Where,

Y- output matrix for n farms.

θ- the total technical efficiency of i^{th} farm.

λ- represents N*1 vector of weights (constants)

X- input matrix for 'n' farms.

y_i- the total farm income of the i^{th} farm in rupees / ha.

x_i - the input vector of x_{1i}, x_{2i}…x_{7i} inputs of i^{th} farm.

x_{1i} - Seed (kg/ha) used on the i^{th} farm

x_{2i} - Total FYM used (in tonnes/ha)

x_{3i} - Total Fertilizer used (kg/ha)

x_{4i} - Total Plant protection chemicals used (in litre/ ha)

x_{5i} - Total Micronutrients used (kg/ha)

x_{6i} - Total man power used (man days/ha) on the i^{th} farm

x_{7i} - Total machine power (hours/ha) used on the i^{th} farm

N_1' is convexity constraint which is a N*1 vector of ones and λ is a N*1 vector of weights (constants) which defines the linear combination of peers of the i^{th} DMU. $1 \leq \phi \leq \infty$ and ϕ - 1 is the proportional increase in output that could be achieved by the i^{th} DMU with the input quantities held constant and $1/\phi$ defines a technical efficiency score which varies between zero and one. If $\phi = 1$ then the farm is said to be technically efficient and if $\phi \leq 1$ the farm lies below the frontier and is technically inefficient.

DEA model for estimation of economic efficiency

Following Coelli *et al.*, (1998), to estimate economic efficiency (EE), a cost minimization DEA model was specified as equation:

$$\min_{\lambda, X_i^E} \; w_i X_i^E$$

$$\text{Subject to } -y_i + Y\lambda \geq 0$$

$$X_i^E - X\lambda \geq 0$$

$$N_1'\lambda = 1$$

$$\lambda \geq 0$$

Where,

w_i- is vector of input price w_{1i}, w_{2i},……,w_{7i} of the i^{th} farm.

X_i^E-is the cost minimizing vector of input quantities for the i^{th} firm.

N refers to total number of firms in the sample

w_{1i} – Total cost of seed (Rs./ha)

w_{2i} – Total cost of FYM (Rs./ha)

w_{3i} – Total cost of fertilizer (Rs./ha)

w_{4i} – Total cost of Plant protection chemicals (Rs./ha)

w_{5i} – Total cost of Micro nutrient (Rs./ha)

w_{6i} – Total cost of human labour (Rs./ha)

w_{7i} – Total cost of machine labour (Rs./ha)

DEA model for estimation of allocative efficiency

Allocative Efficiency was obtained by dividing economic efficiency with technical efficiency.

AE = EE/TE

$$\text{Allocative Efficiency} = \frac{\text{Economic Efficiency}}{\text{Technical Efficiency}}$$

Results and Discussion

Resource use Efficiency of Cotton in The Study Area

The amount of inputs used for the production of cotton and their price or the unit cost of the actual amount of resource combinations data were collected from the sample farmers, helps to estimate the technical, allocative and economic efficiencies. The study used single-output, multiple-input model, input-oriented VRS-DEA to estimate the technical, allocative and economic efficiencies.

Descriptive Statistics of inputs and outputs used by the adopter and non-adopter farmers

To measure farm efficiency, the major inputs used by majority of cotton farmers were considered. Descriptive statistics of output and input variables to analyse the technical, allocative and economic efficiencies were presented in Table 1. In case of adopters the mean farm income obtained was Rs. 43,651.29/ha while the minimum income was Rs. 32,654.00/ha and maximum income obtained was Rs. 56,423/ha. The standard deviation was Rs. 6,039.26/ha.

The average seed, FYM, fertilizer, plant protection chemicals, micro nutrient, human labour and machine power consumed by the farmer was 23kg/ha, 4 tonnes/ ha, 94 kg/ha, 41 lt/ha, 20kg/ha, 12 man-days/ha and 17 hours/ha, respectively.

The mean cost of seed, FYM, fertilizer, plant protection chemicals, micro nutrient, human labour and machine power were Rs. 10,368/ha, Rs. 12,136/ha, Rs. 13,672/ha, Rs. 12,145/ha, Rs. 5,075/ha, Rs. 15,295/ha, and Rs. 25,170/ha, respectively.

In case of non-adopter farmers the mean farm income for non-adopter farmers was Rs. 37,971/ha while the minimum income was Rs. 35,414/ha and maximum income obtained was Rs. 42,324/ha. The standard deviation was Rs. 1,966.375/ha.

The average quantity of seed, FYM, fertilizer, plant protection chemical, micro nutrient, human labour and machine power consumed by the farmer were 23 kg/ha,

Table 1: Descriptive Statistics of inputs, input costs and output of adopter and non-adopter farmers.

	Variables	Adopters				Non-adopters			
		Mean	Min.	Max.	SD	Mean	Min.	Max.	SD
Output variable	Farm income (Rs./ha)	43651.29	32654.00	56423.00	6039.26	37917.77	35414.00	42324.00	1966.38
Input quantity	Seed rate (kg/ha)	23.00	19.00	26.00	1.86	27.65	14.00	44.00	5.14
	FYM used (tonnes/ha)	04.00	02.00	06.00	0.82	2.87	1.52	4.15	0.53
	Fertilizer (kg/ha)	94.00	85.00	98.00	3.61	89.54	47.70	104.80	15.35
	Plant protection chemical used (lt/ha)	41.00	31.00	50.00	4.18	29.78	18.00	40.00	4.28
	Mico nutrient (kg/ha)	20.00	12.00	24.00	3.77	25.66	15.00	35.00	3.96
	Human labour (man-days/ha)	12.00	10.00	15.00	1.41	19.02	05.00	27.00	4.74
	Machine power (hrs/ha)	17.00	15.00	18.00	1.41	32.97	15.00	44.00	5.32
Cost associated with the inputs	Cost of seed (Rs./ha)	10368.00	5642.00	11600.00	1335.10	5851.55	4312.00	6883.00	555.19
	Cost of FYM (Rs./ha)	12136.00	6632.00	13161.00	1440.997	2429.29	1615.00	2976.00	296.85
	Cost of Fertilizer (Rs./ha)	13672.00	6423.00	14680.00	1737.59	2341.58	1259.00	2990.00	404.90
	Cost of Plant protection chemical (Rs./ha)	12145.00	5364.00	15605.00	2830.60	5337.958	3039.00	6936.00	781.34
	Cost of Micro nutrient (Rs./ha)	5075.00	1056.00	8926.00	1766.42	1601.74	1073.00	2975.00	439.13
	Cost of human labour (Rs./ha)	15295.00	5623.00	16959.00	2248.56	3229.92	2509.00	3999.00	292.14
	Cost of machine power (Rs./ha)	25170.00	12648.00	28046.00	3236.77	6314.51	4217.00	9927.00	998.89

SD: Standard deviation; Min.: Minimum, Max.: Maximum

4 tonnes/ha, 94 kg/ha, 41 lt/h, 20kg/ha, 12 man-days/ha and 17 hours/ha, respectively.

The, mean cost of seed, FYM, fertilizer, plant protection chemical, micro nutrient, human labour and machine power were Rs. 10,368/ha, Rs. 12,136/ha, Rs. 13,672/ha, Rs. 12,145/ha, Rs. 5,075/ha, and Rs. 15,295/ha, Rs. 25,170/ha, respectively.

Technical, Allocative and Economic Efficiencies of Adopter and non-adopter farmers

The technical, allocative and economic efficiencies of adopter and non-adopter farmers were estimated and the results were presented in the Table 2.

In case of adopter farmers, the mean technical efficiency was 0.926 which indicated that the farmers could still reduce their input use by 7.40 per cent to produce the same amount of output (as the model was input-oriented). Among the adopter farmers, 12 farmers (20.00 %) were operating at an efficient level 1, 24 farmers (40.00 %) were operating between efficient level 0.9 to 0.99. This implied that almost 60.00 per cent of the farmers were operating at efficient level >0.90. About 24 farmers (40.00%) were operating at 0.80-0.89 level efficiency. None of the farmers were operating below 0.80 level efficiency. This implied that there were more technically efficient farmers than non-efficient farmers.

The analysis of allocative efficiency revealed that the mean allocative efficiency of the adopter farmers was 0.890, indicating that their input costs were, on average, 11.00 percent higher than required to achieve the same level of output. Only 2 farmers (3.33%) were operating at full efficiency and 14 farmers (23.33%) were operating at efficiency level of 0.9-0.99. This implied that only 26.66 per cent farmers were operating at efficient level >0.90. About 44 farmers (73.33%) were operating at efficient level between 0.80-0.89. This implied that total adopter farmers were allocating their inputs at acceptable efficiency range and above allocative efficiency. Since all the farmers were allocatively efficient, there is no much need for the farmers to choose their input mix at given prices to reduce the cost and produce same amount of output.

The mean economic efficiency of the adopter farmers was found to be 0.828 which indicated that the farmers could reduce the cost by 17.20 per cent to produce same amount of output. Only 2 farmers (3.33%) were operating at full efficiency and 5 farmers (8.33%) were operating at efficiency level of 0.9-0.99. This implied that 11.66 per cent farmers were operating at efficient level >0.90. About 33 farmers (55%) were operating at an efficiency level of 0.8-0.89 and 20 farmers (33.33%) were operating at efficiency level 0.7-0.79.

In case of non-adopter farmers, the mean technical efficiency was 0.907 which indicated that, the farmers could still reduce their inputs by 9.30 per cent to produce same quantity of output (as the model is input-oriented). Among the non-adopter farmers, 31 farmers (25.83%) were operating at an efficient level 1, 25 farmers

Table 2: Frequency distribution of adopter and non-adopter farmers on Technical, Allocative and Economic efficiency indices.

DEA Score	Adopters						Non-adopters					
	Technical Efficiency		Allocative Efficiency		Economic Efficiency		Technical Efficiency		Allocative Efficiency		Economic Efficiency	
	FQ	%	FQ	%	FQ	%	FQ	%	FQ	%	FQ	%
1	12	20.00	2	3.33	2	3.33	31	25.83	3	2.50	3.00	2.50
0.90-0.99	24	40.00	14	23.33	5	8.33	25	20.83	5	4.17	5.00	4.17
0.80-0.89	24	40.00	44	73.34	33	55.00	64	53.34	12	10.00	3.00	2.50
0.70-0.79	0	0.00	0	0.00	20	33.34	0	0.00	30	25.00	20.00	16.67
0.60-0.69	0	0.00	0	0.00	0	0.00	0	0.00	61	50.83	31.00	25.83
0.50-0.59	0	0.00	0	0.00	0	0.00	0	0.00	9	7.50	58.00	48.33
<0.49	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Sum	60	100	60	100	60	100	120	100	120	100	120	100
Maximum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	1.00						
Minimum	0.87	0.80	0.77	0.821	0.559	0.554						
Mean	**0.926**	**0.890**	**0.828**	**0.907**	**0.715**	**0.650**						

FQ: Frequency

(20.83%) were operating between efficient level 0.9 to 0.99. This implied that almost 46.66 per cent of the farmers were operating at efficient level > 0.90. About 64 farmers (53.33%) were operating at 0.80-0.89 level efficiency.

The mean allocative efficiency of the non-adopter farmers was 0.714 indicating that their input costs were, on average, 28.60 percent higher than required to achieve the same level of output. Only 3 farmers (2.50%) were operating at full efficiency and 5 farmers (4.17%) were operating at efficiency level of 0.9-0.99. This implied that only 6.67 per cent farmers were operating at efficient level > 0.90. About 12 farmers (10.00%) were operating at 0.80-0.89 level, 30 farmers (25.00%) were operating at 0.70-0.79 level, 61 farmers (50.83%) were operating at 0.60-0.69 level and 9 farmers (7.50%) were operating at efficient level 0.4-0.49. None of the farmers were operating at below 0.40 level.

The mean economic efficiency of the non-adopter farmers was found to be 0.649 which indicated that the farmers could reduce the cost by 35.10 per cent to produce same amount of output. Only 3 farmers (2.50%) were operating at full efficiency and 5 farmers (4.17%) were operating at 0.9-0.99 efficiency level. This implied that 6.67 per cent of farmers were operating at efficient level > 0.90. About 3 farmers (2.50) were operating at efficient level of 0.8-0.89, 20 farmers (16.67%) were operating at 0.7-0.79 efficient level, 31 farmers (25.83%) were operating at efficient level 0.60-0.69 and 58 farmers (48.33%) were operating at 0.50-0.59.

The TE was more than AE and EE for both the adopter and non-adopter farmers. Further, all the three types of efficiency measures viz., TE, AE and EE were more in case of adopter farmers than non-adopter farmers. The large gap between TE AE and EEs of the non-adopter farmers indicated that there was a large scope for increasing the net income of the non-adopter farmers.

The adopter famers were more efficient compared to the non-adopters due to their effective utilization of the recommended doses of the inputs such as optimal quantities of seeds, FYM, fertilizer, plant protection chemicals and micro nutrients. The non-adopters were less efficient as there was unnecessary and excessive input usage. The non-adopters can increase their resource use efficiency by adopting more precise and need-based input application practices.

Conclusion

From the results of DEA, the mean technical, allocative and economic efficiencies were found to be 0.926, 0.890 and 0.828 and 0.907, 0.715 and 0.650 for the adopters and non-adopters, respectively. These results confirm that the adopter farmers are economically efficient and the farmers on an average could reduce their cost by 17.20 per cent to produce same amount of output compared to non-adopters by 35.10 per cent.

The TE was more than AE and EE in both adopter and non-adopter farmers. Further, all the three types of efficiency measures viz., TE, AE and EE were more in adopter farmers than non-adopter farmers. The large gap between TE, AE and EEs of the non-adopter farmers indicates that there is a large scope for increasing the net income of the cotton farmers.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests: Authors have declared that no competing interests exist.

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