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RESEARCH ARTICLE

Technical Efficiency of Rice Farmers in Telangana, India: Data Envelopment Analysis (DEA)

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Abstract: It is known that the inability of the farmers to exploit the available production technologies results in lower efficiencies of production. So, the measurement of technical efficiency in agricultural crops in developing countries like India gained renewed attention in the late 1980s from an increasing number of researchers. Accordingly, the present study has employed Data Envelopment Analysis (DEA) and Malmquist Total Factor Productivity Index to ascertain the technical efficiency of rice productivity (2021-2022) and its changes over the study period (2019-2020 to 2021-2022) respectively in Telangana, India. This study was based on secondary data pertaining to rice productivity (output variable), fertilizer doses (NPK), seed rate, water applied and organic manure (input variables). The findings of Data Envelopment Analysis revealed that the overall mean technical efficiency score across all the Decision-Making Units was 0.860 ranging between 0.592 and 1.000. So, the Decision-Making Units, on average, could reduce their input usage by 14 percent and still could produce the same level of rice output. Further, fertilizers (60.54 kg/ha); seed (5.63 kg/ha); water (234.48 mm) and organic manure (3.76 t/ha) use can be reduced without affecting the current level of rice productivity. Malmquist Total Factor Productivity indices (2019-2020 to 2021-2022) revealed that the mean scores of technical efficiency change, pure technical efficiency change and scale efficiency change are more than one (1.153, 1.042 and 1.009 respectively), unlike technological change (0.983). All the Decision-Making Units showed impressive progress with reference to technical efficiency change (1.112) and it is the sole contributor to Total Factor Productivity change in rice cultivation. The DEA results suggest that farmers should be informed about the use of inputs as per the scientific recommendations to boost the technical efficiency of rice productivity in Telangana. It also calls for policy initiatives for the distribution of quality inputs to the farmers to boost technical efficiency in rice production.

Keywords: Constant returns to scale; Malmquist total factor productivity index; Decision Making Units; Telangana

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1. Introduction

FAO during the International Year of Rice of 2004 stated that "*Rice contributes to many aspects of society and therefore can be considered a crystal or prism through which the complexities of sustainable agriculture and food systems can be viewed. The issues related to rice production should not be viewed in isolation but in the framework of agricultural production systems through ecological and integrated systems*" [1]. This statement highlights rice not only as one of the most important food crops world-wide but also an intricate part of socio-cultural influence of many people's lives. Rice is grown in about 120 countries and China leads other countries in the world with a production of 214 million tonnes followed by India with 116 million tonnes and these two countries together contribute over 50 percent of the world's output in 2019. Nine out of the top ten and 13 out of the top twenty rice-producing countries are in Southeast-Asia [2].

Rice contributed more than 40 percent of the total food grains production in India in 2019 and accounted for 21 percent of global rice production. West Bengal, Uttar Pradesh, Punjab, Andhra Pradesh, Odisha and Telangana are the leading rice producing States in India [3]. Boosting the yields of rice is very much critical for the well-being of millions of rice producers and consumers in India, as around 22 percent of the population still lie Below Poverty Line (BPL) in 2018 [4]. Further, the demand for rice is projected at 137.3 million tonnes by 2050 [5]. To accomplish these goals, the rice yields must be increased by around 42 percent i.e., from the present level of 2393 kg/ha (in 2011-2012) to 3400 kg/ha.

Telangana State is emerging as the 'Rice Bowl of India' because, in a short span of five years, the area under rice cultivation has doubled from 0.91 million hectares in 2014-2015 to 1.93 million hectares in the 2018-2019. Recently, with the completion of Kaleshwaram Lift Irrigation Scheme, the extent of rice cultivation in Telangana has increased in just one year from 1.93 million hectares in 2018-2019 to 2.88 million hectares in 2019-2020 and accordingly, production shot up from 6.6 million tonnes to 10.5 million tonnes during this reference period 2022 [6]. So, the adequate water resources and other inputs like seed, fertilizers subsidy, free power etc., being provided by the State Government enabled the farmers to take up rice cultivation. However, the statistical data available in the offices of Joint Director of Agriculture in Telangana has revealed drastic variations in rice productivity and resources usage. These variations in resources usage contributed to low productivity of rice (compared to potential) and this may arise owing to lower Technical Efficiency (TE). This is an indicator of the presence of technical inefficiency in rice productivity across the districts in Telangana. Considering the socio-economic importance of rice farming in this state, there seems to be a research need for investigating the extent of such inefficiencies. It, therefore, calls for a scientific inquiry on TE of rice production in Telangana, which would be of much relevance for farmers, researchers, policymakers and other stakeholders to take appropriate measures for enhancing TE in rice productivity, efficient management practices and consequent, sustainable agricultural planning. In this context, this study formulated the following three research questions viz., what is the TE of rice productivity across all the districts in Telangana? What is the trend in TEs of rice productivity over a period of time? What input quantities are required to produce at the technically efficient point on the production frontier [4]? So, this study gives an important direction to farmers for employing right combination of productive resources in the rice production programme. Further, the lack of empirical studies in Telangana on this pertinent issue has prompted the researcher to conduct scientific enquiry across the 32 rice producing districts with the following specific objectives:

- To estimate TEs in rice productivity across the districts or Decision-Making Units (DMUs) in Telangana
- To find out the potential for reduction in the levels of critical inputs across the DMUs.
- To analyze the trends in TE and sources of TFP of rice over the study period.

2. Review of Literature

There have been a sizeable number of studies on efficiency measure in the field of agriculture through applying DEA approach because of its non-parametric nature. A review of literature on the application of DEA in measuring efficiency in crop productivity is presented here under.

Tolga et al. (2009) [7] measured TE and determinants of TE of rice farms in Marmara region, Turkey. Their study revealed that mean TE score of sample rice farms was 0.92 and ranged between 0.75 to 1.00 implying that they can reduce the inputs usage by eight per cent without affecting the level of output.

Fabio (2015) [8] studied both technical and scale efficiency in the Italian citrus farming through employing both DEA and Stochastic Frontier Analysis (SFA). The findings revealed that though the estimated TE from SFA is on par with the DEA, the scale efficiency realized from SFA is found higher compared to DEA. Both the models revealed that TE and scale efficiency were positively influenced by farm size, unlike the number of plots of land and location of farm in a less-favoured area.

Sivasankari et al. (2017) [9] employed DEA to analyze the TE of rice farms in Cauvery delta zone of Tamil Nadu. The findings revealed that TE index ranged from 0.41 to 1.00 under both Constant Returns to Scale (CRS) and 0.48 to 1.00 under Variable Returns to Scale (VRS) specifications with mean TEs of 0.76 and 0.81 respectively. Regarding scale efficiency, the majority of the farms (81%) exhibited showed Increasing Return to Scale (IRS). The study also inferred that there is excess use for all inputs especially for fertilizers like potash, phosphorus and farm yard manure among the sample farms.

Bingjun and Xiaoxiao (2018) [10] analyzed rice production efficiency based on DEA-Malmquist Indices in Henan Province of China. The results showed that from the time dimension (2006-2016), the comprehensive TE change, the technological progress change, the pure TE change, the scale efficiency change and the TFP change have not shown much improvement. However, from the perspective of spatial dimension, the TFP of rice in all provinces is less than one, mainly because the production technology was not fully utilized in each area. So, they suggested strengthening research and development, dissemination of advanced production technology, proper allocation of production factors etc., should deserve special attention to ensure efficiency improvement and thereby, food security of the country.

Joseph et al. (2018) [11] employed DEA to measure TE of rice production in the Centre region of Cameroon considering both CRS and VRS assumptions. The findings revealed that the mean TE score is 0.67 and 0.95 at the CRS and VRS respectively and with a mean scale efficiency of 0.70.

Shamsudeen et al. (2018) [4] employed input-oriented DEA to analyze the TE of rice production in northern Ghana for the 2011-2012 cropping season. The mean TE score was 77 percent implying the farmers employed higher doses of inputs viz., chemical fertilizer, seed, weedicides and hired labour than their prescribed optimum. Around 84.4 of the sample farms experienced IRS, while 5.6 per cent experienced Decreasing Returns to Scale (DRS).

Nazir and Abdur (2022) [12] analysed the TFP of cash crops viz., sugarcane, cotton, and rice in Pakistan by employing Malmquist productivity index. The study decomposed the TFP of cash crops into technical change and TE change. The findings showed an increase in the TFP of selected cash crops in Pakistan by 2.2 percent and this is mainly attributed to technical change. So, the researchers emphasized increasing both research and extension investments to provide better seed varieties, better infrastructure, and timely credit facilities.

3. Analytical Framework and Methodology

This study uses a two-step approach. In the first step, the DEA model was employed to measure TE of DMUs as an explicit function of discretionary variables pertaining to Kharif season, 2021-2022. In the second step, DEA-based Malmquist Index was used to analyze the trends in TE of rice productivity during Kharif season across the DMUs over the reference period, 2019-2020 to 2021-2022. This study considered all the 32 DMUs in Telangana considering output variable (rice productivity) and input variables (seed rate, fertilizer doses (NPK), water applied during crop growth period and organic manure). The secondary data on these variables are collected from respective Joint Director of Agriculture Offices at DMU level.

3.1 DEA

This linear programming tool was employed to measure the TE of rice productivity in Telangana considering input-oriented-CRS model [13-15]. In this model, there are 32 DMUs and each DMU uses four inputs (K) and produces one output (M). For the i^{th} DMU, these are represented by the vectors x_i and y_i, respectively. The selected inputs and output are represented by a K × N input matrix denoted by X, and M × N output matrix denoted by Y respectively. For the i^{th} DMU, the efficiency score θ is obtained by solving the linear programming as follows:

$$\min_{\theta\lambda} \theta$$

$$st$$

$$-y_i + Y\lambda \geq 0$$
$$\theta x_i - X\lambda \geq 0$$
$$\lambda \geq 0$$

Here, θ indicates the TE score of input-oriented CRS of the DMU under evaluation. If the value of θ = 1, it implies the DMU is functioning on the production frontier with 100 percent of efficiency and hence, there is no need for changing the level of resources employed in the production. On the contrary, if θ < 1, it implies the DMU under consideration is relatively inefficient and thus, it could reduce the level of inputs usage without affecting the output [9].

3.2 Malmquist TFP Index: Input Oriented, CRS

This index based on DEA is employed to study the trends in TE, technological change, Pure TE change, scale efficiency change and changes in TFP of rice productivity during 2019-2020 to 2021-2022 across the selected 32 DMUs. So, the average values of the selected output and input variables during this reference period are subjected to DEA-based Malmquist Index analysis. The change in productivity from the period t to $t + 1$ is calculated using the following formula [9,16]:

$$M_1^{t+1}(y^{t+1}, x^{t+1}, y^t, x^t) = \left[\frac{D_1^t(y^{t+1}, x^{t+1})}{D_1^t(y^t, x^t)} \text{ X } \frac{D_1^{t+1}(y^{t+1}, x^{t+1})}{D_1^{t+1}(y^t, x^t)}\right]^{1/2} \quad (1)$$

where, M_1 = Malmquist Productivity Change Index

D_1 = Input distance functions [15]

y = the level of output(s)

x = the level of input(s); and

t = time

Equation (1) is decomposed as:

$$M_1^{t+1}(y^{t+1}, x^{t+1}, y^t, x^t) = \left[\frac{D_1^{t+1}(y^{t+1}, x^{t+1})}{D_1^t(y^t, x^t)} * \left[\frac{D_1^t(y^{t+1}, x^{t+1})}{D_1^{t+1}(y^{t+1}, x^{t+1})} * \frac{D_1^t(y^t, x^t)}{D_1^{t+1}(y^t, x^t)}\right]\right]^{1/2} \quad (2)$$

The first term on the RHS of the above equation indicates the change in input-based TE between the years *t* and *t* + 1, while the second term indicates the change in technology between the selected periods. From the above Equation (2), it can be inferred that the product of change in TE and technological change gives a measure of change in TFP. If the TFP is > 1, it implies the TFP is increasing during the selected periods (*t* and *t* + 1) and *vice versa* and if the TFP = 1, it implies no change [15]. To obtain the change in Malmquist Indices, the following series of Linear Programing Problems (LPPs) are to be solved [16]:

$$\left[D_I^t(y_t, x_t)\right]^{-1} = min_{\theta\lambda}\theta \quad (3)$$

st

$$-y_{it} + Y_t\lambda \geq 0$$
$$\theta x_{it} - X_t\lambda \geq 0$$
$$\lambda \geq 0$$

$$\left[D_I^{t+1}(y_{t+1}, x_{t+1})\right]^{-1} = min_{\theta\lambda}\theta \quad (4)$$

st

$$-y_{i,t+1} + Y_{t+1}\lambda \geq 0$$
$$\theta x_{i,t+1} - X_{t+1}\lambda \geq 0$$
$$\lambda \geq 0$$

$$\left[D_I^{t+1}(y_t, x_t)\right]^{-1} = min_{\theta\lambda}\theta \quad (5)$$

st

$$-y_{it} + Y_{t+1}\lambda \geq 0$$
$$\theta x_{it} - X_{t+1}\lambda \geq 0$$
$$\lambda \geq 0$$

$$\left[D_I^t(y_{t+1}, x_{t+1})\right]^{-1} = min_{\theta\lambda}\theta \quad (6)$$

st

$$-y_{i,t+1} + Y_t\lambda \geq 0$$
$$\theta x_{i,t+1} - X_t\lambda \geq 0$$
$$\lambda \geq 0$$

These LPPs are solved for each firm in the sample. Therefore, given the number of periods (*T*) and number of observations (*N*), [*N* × (3*T*-2)] problems are to be solved.

This study considered all the 32 districts (as the DMUs) in Telangana and the relevant secondary data are obtained from respective Joint Director of Agriculture Offices. Rice yield (kg/ha) is considered as the output, whereas seed rate, fertilizer doses (NPK), annual rainfall received (mm) and organic manure are considered as inputs. The average values of the output and input variables (2019-2020 to 2021-2022) are collected for the DMUs and subjected to DEA and DEA-based Malmquist TFP Index analysis for estimating the TE and change in TE respectively. The efficiency analysis and Malmquist Index for efficiency change over time have been done using the DEAP version 2.1 program developed by Coelli, 1996 [15].

3.3 Sample Adequacy Test

According to Cooper et al., 2007 [17], the thumb rules for sample size acceptable for conducting DEA should be either greater than or equal to the product of inputs (X) and outputs (Y) or the sample size should be at least three times the sum of the number of X and Y variables. So, considering X = 4 and Y = 1, the sample size of 32 DMUs in Telangana confirms the sample adequacy for conducting DEA.

4. Results and Discussion

4.1 Summary Statistics of Output and Input Variables

Table 1 shows that the average productivity of rice in Telangana was estimated as 3288.28 kg/ha with maximum and minimum productivity levels of 3705 kg/ha and 2720 kg/ha respectively with the estimated Coefficient of Variation (CV) of 59.928 percent. There exist larger variations across the DMUs in terms of inputs usage viz., fertilizer doses, seed rate, water applied and organic manure. Regarding the quantity of fertilizers (NPK) applied, it ranged from 110 kg/ha to 350 kg/ha with an average value of 263.37 kg/ha and CV of 55.798 percent. The application of chemical fertilizers is on the higher side among all the DMUs compared to the recommended dosages **(**NPK @ 120:40:40 kg ha^{-1} for short duration varieties; NPK @ 150:50:60 kg ha^{-1} for medium duration varieties and NPK @ 150:50:80 kg ha^{-1} for long duration varieties). Similarly, average quantity of water applied was 1190.01 mm with minimum and maximum values of 780 mm and 1670 mm respectively and with a CV of 41.579 percent. For the majority of the DMUs (87%), the actual quantity of water applied is higher than the scientific recommendation of 1200 mm to 1250 mm. The quantity of seed used pitches between 17 kg/ha and 28 kg/ha with a mean value of 23.47 kg/ha and with a CV of 38.508 percent. A close examination of the data collected, the actual seed used by all the DMUs is considerably higher compared to the recommended level of 20 kg/ha. However, the CV is slightly lower with respect to organic manure applied for rice cultivation (24.617%) and across the DMUs it varied between 2 t/ha to 12 t/ha with an average of 8.37 t/ha. The higher CVs of inputs is an indication of the presence of technical inefficiency in contributing to the productivity of rice across the DMUs in Telangana. Again for the majority of the DMUs, the quantity of organic manure applied is higher compared to the recommended dosage of 8 t/ha to 10 t/ha. Though the application of this input is on the higher side, it is heartening that the farmers realized the importance of organic farming in producing both cost-effective and quality output.

4.2 DEA-Input-Oriented CRS

The results of CRS TE scores (θ) along with benchmarking DMUs and peer lambda weights (λ_j) for the DMUs under evaluation are presented in Table 2. The findings revealed that only nine out of 32 DMUs namely, Karimnagar, Jogulamba Gadwal, Kamareddy, Khammam, Mahabubnagar, Medak, Medchal-Malkajgiri, Narayanpet and Suryapet received TE score of '1'. This implies they are the best performing DMUs in Telangana, as they are operating on the efficiency frontier in the peer group. For the remaining 23 DMUs, the TE scores are less than one ranging between 0.592 (Warangal-Rural) to 0.931 (Jagtial) with a mean TE score of 0.806. This implies presence of relative technical inefficiency in rice productivity, as these 23 DMUs are operating below the efficiency frontier. So, these 23 DMUs could reduce current level inputs to the tune of 19.4 percent without affecting the rice productivity. The overall mean TE score for all the 32 DMUs was estimated as 0.860 indicating relative technical inefficiency is to the extent of 14 percent. This means that, on average, the DMUs can check over-use of current level input resources to the tune of 14 percent without affecting the rice productivity in the State. The DMU, Warangal-Rural is with the lowest TE score of 0.592 followed by Vikarabad (0.611), Mulugu (0.661), Mancherial (0.717) etc., and all are lying at the bottom of the performance ladder (Table 3). So, these DMUs could reduce the current level of input usage by 40.80, 38.90, 33.90 and 28.30 percent respectively without affecting their corresponding rice productivity levels. For the inefficient DMUs (θ < 1), the benchmarking DMUs are given in Column 4 and it will guide the former to reduce their inputs usage corresponding to the benchmarking DMUs [9,10]. For example, Suryapet and Kamareddy are the benchmarking DMUs for Adilabad with respective lambda (λ_j) weights of 0.903 and 0.023. With the λ_j weights, the benchmarking DMUs form linear combinations with the inefficient DMUs in terms of efficiency perspective. For the efficient DMUs (with TE score of 1.000), the benchmarking DMUs are peers of themselves with λ_j weights of 'one'.

The comparative picture of efficient and inefficient DMUs in terms of TE scores (Figure 1) indicate that the dark color bars represent the DMUs (9) operating on the efficiency frontier (with TE scores of '1') and the light color bars denote the DMUs (23) lying below the efficiency frontier (with TE scores of '< 1'). So, the vertical gap between efficient and inefficient DMUs indicates the extent of technical inefficiencies of 23 DMUs.

4.3 Determining Optimal Level of Inputs Utilization from the CRS Model

From Table 2, it was inferred that there are nine technically efficient DMUs and 23 technically inefficient DMUs. Accordingly, DMU-wise projected input quantities and possible reductions across inefficient DMUs were computed [14,15] to realize higher TE scores without affecting their current level of rice productivity (Table 4). The projected input quantities indicate the minimum quantities of selected inputs required across the DMUs to produce technically efficient output on the production frontier. So, the difference between actual and projected quantities of inputs (obtained from the one-stage DEA) indicates the possible input quantity reductions. For example, the actual use of

Table 1. Summary statistics of output and input variables (2021-2022).

Item	Minimum	Maximum	Mean	Std. Deviation	CV
Rice productivity (kg/ha)	2720	3705	3288.28	1970.60	59.928
Fertilizer Use (NPK) (kg/ha)	110	350	263.37	146.96	55.798
Seed rate (kg/ha)	17	28	23.47	9.04	38.508
Water applied (mm)	780	1670	1190.01	494.79	41.579
Organic manure (t/ha)	2	12	8.37	2.06	24.617

Table 2. Results of input-oriented CRS.

Sl. No.	Districts	CRS Technical Efficiency (θ)	Benchmarking Districts	Peer Weights (λ_j) in Order of Benchmarking Districts
1	Adilabad	0.828	Suryapet, Kamareddy	0.903, 0.023
2	Bhadradri Kothagudem	0.875	Medak, Karimnagar, Khammam	0.179, 0.631, 0.214
3	Karimnagar	1.000	Karimnagar	1.000
4	Jagtial	0.931	Kamareddy	0.920
5	Jangaon	0.803	Karimnagar, Medchal-Malkajgiri, Narayanpet	0.668, 0.028, 0.288
6	Jayashankar Bhupalpally	0.858	Suryapet, Kamareddy	0.334, 0.566
7	Jogulamba Gadwal	1.000	Jogulamba Gadwal	1.000
8	Kamareddy	1.000	Kamareddy	1.000
9	Khammam	1.000	Khammam	1.000
10	Kumuram Bheem	0.812	Khammam, Karimnagar, Suryapet	0.558, 0.403, 0.009
11	Mahabubabad	0.868	Kamareddy Karimnagar, Mahabubnagar, Bhadradri Kothagudem	0.357, 0.371, 0.137, 0.214
12	Mahabubnagar	1.000	Mahabubnagar	1.000
13	Mancherial	0.717	Karimnagar, Kamareddy, Suryapet	0.343, 0.505, 0.035
14	Medak	1.000	Medak	1.000
15	Medchal-Malkajgiri	1.000	Medchal-Malkajgiri	1.000
16	Mulugu	0.661	Khammam, Karimnagar, Suryapet	0.255, 0.469, 0.183
17	Nagarkurnool	0.889	Narayanpet, Mahabubnagar	0.604, 0.365
18	Nalgonda	0.834	Narayanpet, Jogulamba Gadwal, Suryapet	0.631, 0.120, 0.196
19	Narayanpet	1.000	Narayanpet	1.000
20	Nirmal	0.724	Suryapet, Narayanpet, Mahabubnagar, Kamareddy	0.594, 0.036, 0.094, 0.245
21	Nizamabad	0.848	Suryapet, Karimnagar, Kamareddy	0.077, 0.523, 0.356
22	Peddapalli	0.838	Karimnagar, Narayanpet, Kamareddy Suryapet	0.028, 0.319, 0.488, 0.226
23	Rajanna Sircilla	0.836	Karimnagar, Mahabubnagar, Kamareddy, Narayanpet	0.583, 0.115, 0.161, 0.136
24	Rangareddy	0.869	Karimnagar, Medchal-Malkajgiri, Narayanpet	0.174, 0.089, 0.694
25	Sangareddy	0.775	Karimnagar, Narayanpet, Mahabubnagar	0.396, 0.456, 0.205
26	Siddipet	0.819	Karimnagar, Medak, Narayanpet, Suryapet	0.323 0.01,1 0.059, 0.408
27	Suryapet	1.000	Suryapet	1.000
28	Vikarabad	0.611	Suryapet, Narayanpet, Jogulamba Gadwal	0.101, 0.524, 0.211
29	Wanaparthy	0.917	Narayanpet	0.947
30	Warangal (Rural)	0.592	Suryapet, Narayanpet, Kamareddy, Mahabubnagar	0.021, 0.602, 0.224, 0.030
31	Warangal (Urban)	0.804	Kamareddy, Mahabubnagar, Suryapet	0.195, 0.533, 0.201
32	Yadadri Bhuvanagiri	0.819	Suryapet, Narayanpet, Jogulamba Gadwal	0.017, 0.895, 0.173
Average of all districts		0.860		

Source: Authors' estimation from DEAP version 2.1 [15].

Table 3. Frequency distribution and summary statistics on overall TE, pure TE and Scale efficiency measures of selected DMUs.

Efficiency level	No. of DMUs	Per cent	DMUs
0.501-0.600	1	3.12	Warangal (rural)
0.601-0.700	2	6.25	Mulugu, Vikarabad
0.701-0.800	3	9.38	Mancherial, Niirmal, Sangareddy
0.801-0.900	15	46.88	Adilabad, Bhadradri Kothagudem, Jangaon, Jayashankar Bhupalpally, Kumuram Bheem, Mahabubabad, Nagarkurnool, Nalgonda, Nizamabad, Peddapalli, Rajanna Siricilla, Rangareddy, Siddipet, Warangal (urban), Yadadri Bhuvanagiri
0.901-0.999	2	6.25	Jagtial, Wanaparthy
1.000	9	28.13	Karimnagar, Jogulamba Gadwal, Kamareddy, Khammam, Mahbubnagar, Medak, Medchal-Malkajgiri, Narayanpet, Suryapet
Total	32	100.00	
Minimum	0.592		
Maximum	1.000		
Mean	0.860		

Source: Authors' estimation from DEAP version 2.1 [15].

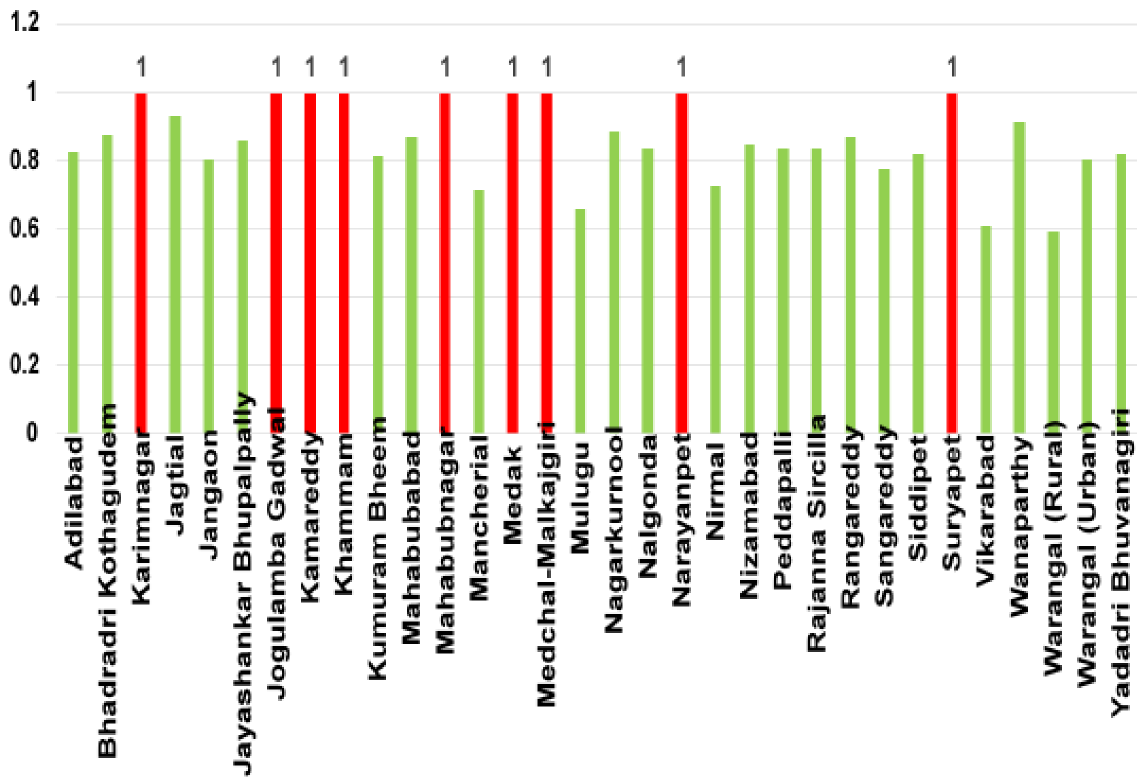

Figure 1. Position of the DMUs in relation to TE scores.

fertilizers, seed rate, water applied and organic manure for the DMU, Adilabad are 205.935 kg/ha, 32.67 kg/ha, 1511.301 mm and 10.215 t/ha respectively, whereas the projected input values obtained from the model for maintaining the same productivity (3124.73 kg/ha) are 145.395 kg/ha, 27.04 kg/ha, 1276.821 mm and 6.455 t/ha respectively. So, the estimated differences between the actual and projected input values (fertilizers 60.54 kg/ha; seed use 5.63 kg/ha; water applied 234.48 mm and organic manure 3.76 t/ha) indicate their excess use in rice production. Hence, this excess use of inputs should be reduced for Adilabad without affecting rice productivity. The same explanation can be offered for other technically inefficient DMUs. However, for the efficient DMUs with TE score 1.000, the gap between actual and projected input usage is around zero, as they are already operating on the production frontier (the best performing DMUs) and hence, there is no scope for reduction in the existing level of inputs usage. At the pooled (State) level i.e., considering the average of all the DMUs, there is overuse of fertilizers, seed use, water applied and organic manure to the tune of 53.998 kg/ha, 6.528 kg/ha, 86.436 mm and 2.249 t/ha respectively, as the production scenario of rice in dominated by technically inefficient DMUs (23) compared to only nine technical efficient DMUs.

So, it is felt appropriate to compare the extent of inputs usage between technically efficient DMUs and technically inefficient DMUs in terms of rice productivity in Telangana. As shown in Table 5, the efficient DMUs (n = 9) employed an average of 170.184 kg/ha of fertilizer, 21.667 kg/ha of seed, 1275.986 mm of water applied and 5.000 t/ha of organic manure to produce a yield of 3317 kg/ha of rice. However, for the inefficient DMUs (n = 23), to move up to the production level of the efficient DMUs, they should check excess application of fertilizers by 40.105 kg/ha, seed by 3.724 kg/ha, water use by 36.100 mm and organic manure by 2.870 t/ha in order to boost rice productivity by 778 kg/ha [4].

4.4 Trends in TE of DMUs-Malmquist TFP Index

Table 6 portrayed the Malmquist indices for each DMU during the period 2019-2020 to 2021-2022 [18]. The findings revealed that with reference to TE change index, 78 percent of the DMUs have made progress (TE change value > 1.000) and the remaining 22 percent of DMUs have regressed (TE change value < 1.000). The top three DMUs that showed progress with reference to TE change include: Nizamabad (48.3%), Nagarkurnool (45.5%) and Sangareddy (43.4%) and the top three DMUs that are regressed in terms of TE change are Kumuram Bheem (30.3%), Jagtial (22.2%) and Khammam (19.5%). It is heartening that the mean score for TE change in Telangana is more than 1 (i.e. 1.153) and this shows that the DMUs as a whole have witnessed an impressive performance in TE change of rice productivity during the reference period [9,10,16].

However, it is disappointing that 56% of the DMUs have regressed with reference to technological change during the above reference period and hence, the mean score of technological index in Telangana is less than one (0.983). The top three DMUs that are regressed include: Mulugu, Medak and Narayanpet with 13.6 percent, 12.9 percent and 12.8 percent respectively. It is found interesting that majority of the DMUs have shown progress with reference to pure TE change (53%) and scale efficiency change (59%). Further, 75 percent of the DMUs showed progress with reference to TFP change and the remaining 25 percent of DMUs have regressed. The top three DMUs viz., Nizamabad, Karimnagar and Sangareddy have enjoyed TFP growth of 42.1 percent, 40.1 percent and 35.2 percent respectively. At the state level, the results are found encouraging with reference to TE change (15.3%), pure TE change (4.2%), Scale efficiency change (0.9%) and TFP change (11.2%). So, on comparing the TE change and technological change, it can be inferred that the progress in TFP change is purely from TE change during the reference period.

The break-up of Malmquist indices across the selected periods viz., 2019-2020 to 2021-2022 (Table 7) revealed that TE change has shown increasing trend from 1.139 (2019-2020) to 1.179 (2021-2022) with mean TE change of 1.153. This shows that there is a gradual progress in terms of TE change for enhancing rice productivity in the State during the overall reference period. On the contrary, the mean technological change was regressed during the reference period with 0.983. Though technological change was marginally progressed (2.7%) during 2021-2022 compared to 2020-2021, the mean technological change is regressed during the overall reference period. It is also interesting that the DMUs have marginally progressed in terms of pure TE change (4.2%) and Scale Efficiency change (0.9%) during the reference period. The TFP change has witnessed progress in the State with an average value of 1.112. Considering these trends, it can be inferred that at State level, pure TE change and scale efficiency change have almost remained stagnant and hence, the gain in TFP of rice in Telangana is solely due to TE change of inputs over time.

Table 4. Results of input-oriented CRS: Single stage calculation.

S.No	Districts	Projected Input Quantities				Possible Inputs Reduction (Actual - Projected)			
		Fertilizer Use (NPK) (kg/ha)	Seed rate (kg/ha)	Water applied (mm)	Organic manure applied (t/ha)	Fertilizer Use (NPK) (kg/ha)	Seed rate (kg/ha)	Water applied (mm)	Organic manure applied (t/ha)
1	Adilabad	145.395	27.040	1276.821	6.455	60.540	5.630	234.480	3.760
2	Bhadradri Kothagudem	181.191	36.177	1399.781	3.501	51.620	5.160	130.776	1.000
3	Karimnagar	145.670	38.000	1232.784	3.000	0.000	0.000	0.000	0.000
4	Jagtial	100.580	34.959	1562.051	5.520	14.840	5.370	42.354	4.960
5	Jangaon	142.383	36.562	1122.035	3.212	69.900	14.100	91.800	0.900
6	Jayashankar Bhupalpally	114.741	31.185	1418.841	5.733	37.860	5.150	129.900	2.540
7	Jogulamba Gadwal	201.000	28.000	871.146	7.000	0.000	0.000	0.000	0.660
8	Kamareddy	109.330	38.000	1697.940	6.000	0.000	0.000	0.000	0.660
9	Khammam	205.670	29.330	1649.358	5.000	0.000	0.000	0.000	0.660
10	Kumuram Bheem	174.908	31.947	1429.609	4.061	80.860	7.390	185.790	1.220
11	Mahabubabad	137.995	40.209	1400.504	5.207	42.020	6.120	71.058	0.920
12	Mahabubnagar	115.000	39.000	1025.550	8.000	0.000	0.000	0.000	-0.660
13	Mancherial	110.722	33.239	1328.369	4.305	87.220	13.090	194.862	2.720
14	Medak	252.330	33.000	1499.022	3.000	0.000	0.000	0.000	-0.660
15	Medchal-Malkajgiri	208.000	53.000	1217.412	2.000	0.000	0.000	0.000	0.000
16	Mulugu	149.843	30.627	1250.676	3.966	153.640	15.710	290.424	3.400
17	Nagarkurnool	124.410	34.599	930.028	5.341	31.180	7.070	38.850	3.320
18	Nalgonda	141.268	30.309	953.896	4.739	56.140	6.020	63.162	5.860
19	Narayanpet	136.330	33.670	918.846	4.000	0.000	0.000	0.000	-0.660
20	Nirmal	136.427	31.388	1359.256	6.520	103.820	11.950	172.374	4.300
21	Nizamabad	127.272	35.636	1354.761	4.242	45.460	6.360	120.462	1.520
22	Peddapalli	136.674	36.894	1466.075	5.869	52.660	7.110	94.134	2.260
23	Rajanna Sircilla	134.357	37.354	1235.797	4.181	52.620	7.310	80.676	1.640
24	Rangareddy	138.404	34.680	960.221	3.475	41.860	6.650	48.396	1.060
25	Sangareddy	143.316	38.366	1116.504	4.648	83.360	12.970	108.246	2.700
26	Siddipet	122.589	26.480	1029.404	4.095	54.160	5.850	75.798	1.820
27	Suryapet	158.330	29.000	1371.816	7.000	0.000	0.000	0.000	0.000
28	Vikarabad	129.762	26.471	803.320	4.276	187.140	16.860	170.538	6.120
29	Wanaparthy	129.065	31.876	869.879	3.787	70.540	5.790	26.154	7.760
30	Warangal (Rural)	113.414	30.574	993.618	4.142	156.500	21.090	228.534	6.380
31	Warangal (Urban)	114.463	34.042	1153.809	6.844	55.740	8.290	93.636	4.320
32	Yadadri Bhuvanagiri	159.532	35.477	996.773	4.913	138.260	7.860	73.548	1.500
Average of all Districts		**145.012**	**33.972**	**1215.497**	**4.814**	**53.998**	**6.528**	**86.436**	**2.249**

Source: Authors' estimation from DEAP version 2.1 [15].

Table 5. Comparison of average input use between inefficient and efficient farmers in Telangana.

Input use	Number of DMUs	Mean TE score	Fertilizer Use (NPK) (kg/ha)	Seed rate (kg/ha)	Water applied (mm)	Organic manure applied (t/ha)	Yield (kg/ha)
Average of efficient DMUs	9	1.000	170.184	21.667	1275.986	5.000	3317
Average of inefficient DMUs	23	0.806	210.289	25.391	1312.086	7.870	2539

Source: Authors' estimation from DEAP version 2.1 (Coelli et al., 1996 [15]).

Table 6. Malmquist index summary for district means.

Districts	TE Change	Technological Change	Pure TE Change	Scale Efficiency Change	TFP Change
Adilabad	0.879	0.979	0.867	1.013	0.861
Bhadradri Kothagudem	1.217	0.961	0.950	1.070	1.209
Karimnagar	1.410	1.092	1.000	1.010	1.401
Jagtial	0.778	1.042	0.855	0.910	0.811
Jangaon	1.161	0.957	1.115	1.042	1.112
Jayashankar Bhupalpally	1.117	1.048	0.863	0.970	1.108
Jogulamba Gadwal	1.113	0.996	1.000	0.941	1.108
Kamareddy	1.084	1.044	1.055	1.027	1.132
Khammam	0.805	0.979	0.853	0.944	0.788
Kumuram Bheem	0.697	0.918	0.726	0.960	0.640
Mahabubabad	0.826	1.015	1.000	0.826	0.838
Mahabubnagar	1.254	0.972	1.044	1.010	1.211
Mancherial	1.290	0.964	1.417	0.910	1.317
Medak	1.340	0.871	1.280	1.047	1.303
Medchal-Malkajgiri	1.390	1.014	1.044	1.044	1.284
Mulugu	1.113	0.864	1.084	1.026	1.064
Nagarkurnool	1.455	0.968	1.074	0.964	1.002
Nalgonda	1.061	1.010	1.012	1.049	1.072
Narayanpet	0.862	0.872	1.000	0.862	0.752
Nirmal	1.170	0.924	1.000	1.170	1.162
Nizamabad	1.483	1.000	1.265	1.123	1.421
Peddapalli	1.333	0.996	1.186	1.124	1.328
Rajanna Sircilla	1.123	0.952	0.953	0.992	1.048
Rangareddy	1.343	1.002	1.100	1.039	1.345
Sangareddy	1.434	1.015	1.250	0.987	1.352
Siddipet	1.165	1.046	1.068	1.090	1.089
Suryapet	1.026	0.970	1.000	1.026	0.995
Vikarabad	1.043	1.017	0.958	1.088	1.060
Wanaparthy	1.275	1.009	1.036	1.133	1.211
Warangal (Rural)	1.356	0.966	1.202	0.961	1.316
Warangal (Urban)	1.331	1.006	1.151	0.896	1.298
Yadadri Bhuvanagiri	0.954	0.983	0.922	1.035	0.938
Average of all Districts	**1.153**	**0.983**	**1.042**	**1.009**	**1.112**

Note: All Malmquist index averages are geometric means.
Source: Authors' estimation from DEAP version 2.1 [15].

Table 7. Malmquist index summary of annual means.

Year	TE Change	Technological Change	Pure TE Change	Scale Efficiency Change	TFP Change
2019-2020	1.139	1.029	1.038	1.019	1.089
2020-2021	1.140	0.947	1.033	0.986	1.120
2021-2022	1.179	0.974	1.055	1.023	1.127
Mean	**1.153**	**0.983**	**1.042**	**1.009**	**1.112**

Note: All Malmquist index averages are geometric means.
Source: Authors' estimation from DEAP version 2.1 [15].

5. Summary and Conclusions

Input-oriented DEA Model with CRS was employed in this study to analyze the TE in rice productivity in Telangana. Out of 32 DMUs considered, only nine DMUs are found technically efficient. The overall TE score for Telangana is 0.860 implying that the DMUs, on average, could reduce their inputs usage by 14 percent without affecting their current level of rice productivity. Compared to technically efficient DMUs, inefficient DMUs have to check the use of inputs viz, fertilizer use by 40.105 kg/ha, seed use by 3.724 kg/ha, water use by 36.100 mm and organic manure use by 2.870 t/ha in order to boost yield by 778 kg/ha and to reach on the production frontier. Malmquist index analysis concluded that the progress in TFP change during 2019-2020 to 2021-2022 was purely due to TE change only. During this period, on average, the technological change has regressed and pure TE change and scale efficiency change have almost remained stagnant.

6. Policy Recommendations

Policy suggestions from this study include: dissemination of modern production technologies to the farmers, capacity building of farmers on Good Agricultural Practices, supply of quality inputs to farmers at affordable prices etc., which should deserve special attention. The poor and marginalized farmers cultivating rice in the State must be encouraged to join Farmer-Producer Organizations (FPOs) for availing need-based assistance, participate in various training programs and benefit from strengthened backward linkages to enhance TE of inputs usage. Further, to boost the technological change, the Government should enhance investments both in research and extension. The enabling environment in the State should be conducive to promoting private sector agricultural investments [19]. The coordination between demand-driven research and technology dissemination should also be given priority.

Conflict of Interest

There is no conflict of interest.

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