Efficiency of Rice Farms under Different Cultivation Systems : A Stochastic Frontier Cost Approach

H. A. Bindu[1] and K. B. Umesh[2]
[1]Department of Agricultural Economics, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
[2]Director of Research, University of Agricultural Sciences, GKVK, Bengaluru - 560 065
e-Mail : bindudumbi1696@gmail.com

Authors Contribution

H. A. Bindu : Conceptualization, investigation, analysis of data and draft preparation ;
K. B. Umesh : Conceptualization, data curation, supervision and draft correction

Corresponding Author :
H. A. Bindu
Department of Agricultural Economics, College of Agriculture, UAS, GKVK, Bengaluru

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Abstract

The paper has examined the efficiency of growing rice under different cultivation systems in Mandya district of Karnataka, using the data collected from 30 farmers under each of the cultivation systems namely, conventional, SRI (System of Rice Intensification), aerobic and DSR (Drum Seeded Rice) method. In total, the sample size was 120 rice growing farmers. The data was analysed using stochastic frontier cost function to estimate the cost efficiency of the farmers and to examine the factors influencing cost inefficiency. The results revealed that cost of seeds, fertilizers, human labour and machine labour had significant influence on cost of production. The variables such as age (0.239), landholding (0.022) and experience (0.215) in farming influenced cost inefficiency in conventional rice cultivation. Membership in organization (-0.075) and access to extension services (-0.289) were significant in explaining cost efficiency in SRI method. Education (-0.310) was the major factor which significantly contributed to the cost efficiency of aerobic farmers. Whereas, in DSR method age (-0.200) and access to extension services (0.083) were the significant factors. The mean cost or allocative efficiency score in aerobic was 0.94, which was highest among all the systems followed by SRI, DSR and conventional method with scores of 0.92, 0.88 and 0.55, respectively.

Keywords : Rice farms, Cultivation system, Cost efficiency, Stochastic frontier

Rice is a staple food of people in most of the countries of the world and is a very important and essential part of the food system in many countries. India is the second largest producer of rice in the world after China. In India, rice is grown on an area of 45,769 thousand hectares with production of about 124 million tonnes (www.indiastat.com). It is the food cereal which made countries to overcome the problems of hunger and starvation and has certainly played a major role in taking out the people out of food insecurity. Paddy crop holds the key for food security of the country (Bora *et al.,* 2021). Despite its vital role, the rice cultivation system has become one of the major sources for greenhouse gas emission from agriculture and also a cause for higher water consumption. The different rice cultivation systems like aerobic, SRI (System of Rice Intensification), dry seeded rice cultivation, alternate wetting and drying etc. help in yielding higher returns and reducing costs. Adopting a system which increases yield, reduces water consumption, reduces costs *etc.* will aid in sustainable rice production with increased efficiency.

Efficiency means producing maximum output from given level of inputs with respect to production is concerned. Cost or allocative efficiency is producing output at minimum possible costs and with given input prices. Measuring efficiency will help in knowing what amount of resources can be saved by following a particular system of cultivation, which is reflected in the reduced costs. Efficiency can be measured for an individual farm or a group of farms or farms practicing different methods of cultivation. A better understanding and measurement of efficiency in agriculture is required in the context of lower availability of key resources and production factors, such as land or water in adequate quantity and quality (Singh *et al.,* 2020). Factors that influence the farming system efficiency can be distinguished as controlled (farmer's managerial skill) and uncontrolled factors (natural factors, price and agriculture institution). The integration of all of the variables together, will create the level of efficiency that can be achieved (Hidayah *et al.,* 2013). Farm level inefficiency is likely to be affected by exogenous factors, *i.e.* factors that are neither inputs nor outputs of the production process, but nonetheless affect the farm performance (Bhattacharyya, 2016). So, it is important to study the variables which influence inefficiency. It is also necessary to know the outcome of different cultivation systems to suggest adaptation strategies. In this climate change scenario, farmers must be able to adapt coping strategies to ensure long-term output and these adaptation measures can help people minimize their susceptibility and improve their 'socio-economic status' and 'quality of life' (Pooja *et al.,* 2022).

Cultivation system like SRI method is considerably more profitable than traditional method due to low input expenditure. The total cost of cultivation was higher in traditional method (Rs.14014.54/ac) than SRI method *i.e.* Rs.12154.63/ac (Agarwal *et al.,* 2018). Thus, cost efficiency analysis will reveal the method of cultivation to be practised. Vinay *et al.* (2016) analysed the impact of direct seeded rice (DSR) on economics of paddy crop in Haryana. The net return was higher in DSR (Rs.60105/ha) as compared to transplanted rice (Rs.57532.5/ha) and BC ratio was 2.13 in DSR while it was only 1.94 in transplanted rice. This indicates the decreased costs due to increase in efficiency. Moreover, efficiency analysis is also an important input to the policy makers. The aerobic rice cultivating farms were more technically and economically efficient compared to conventional rice cultivating farms. Effective policies to promote and create awareness about aerobic rice can boost the rice production and productivity sustainably. The focus should be given to optimal allocation of resources which enhances the farm productivity and returns (Kumar *et al.,* 2021). This highlights the requisite of cost efficiency analysis.

In this regard, the study made an attempt to estimate the cost efficiency of different rice cultivation systems and identify the system which is cost or allocatively most efficient. It also examined the influence of socio-economic characteristics on cost inefficiency under different rice cultivation system.

Study Area and Selection of Farmers

The study was carried out in Mandya district of Karnataka, which is one of the major producers of rice in Southern Karnataka. Purposive sampling was used to sample the farmers for the study. The primary data was collected from 120 farmers consisting of 30 farmers from each cultivation system namely, conventional rice cultivation, SRI (System of Rice Intensification), aerobic and DSR (Drum Seeded Rice) method. At first the villages practicing these cultivation systems were selected and then the farmers were selected randomly. The data was collected from the respondents through personal interview method using pre-tested, well-structured schedule to achieve the objectives of the study. The required information regarding age, education, land holdings, costs incurred, input usage *etc.* in rice cultivation was collected for the agricultural year 2021-22.

Analytical Tools Used

Efficiency Analysis

Efficiency analysis orders decision-making units such as firm or a farm, by comparing all resources engaged in production and the costs incurred to produce a given set of outputs and building a frontier based on the input costs. The Cobb-Douglas Stochastic Frontier Cost (SFC) approach was used for assessing the cost efficiency of rice farmers under different rice cultivation system, following the Coelli (1996) model as follows:

$$\ln C_i = \alpha_0 + \sum_{j=1}^{4} \alpha j \ \ln Xji + (v_i + u_i)$$

where, ln denotes natural logarithm. C_i is the total production cost of the farm i measured in rupees per acre, X_{1i} is the cost of seeds (Rs./acre), X_{2i} is the cost of fertilizers used (Rs./acre), X_{3i} is human labour cost and X_{4i} is the machine labour cost. v_i is a symmetric, identically and independently distributed N $(0,\sigma^2_v)$ error term. It represents random variation in production due to random exogenous factors, such as measurement errors and statistical noise. u_i is a non-negative error term. It reflects cost inefficiency relative to the stochastic frontier.

The computer programme FRONTIER Version 4.1 was used to estimate the model and to obtain the maximum likelihood estimates of the SFP function. The calculation of MLE requires (Coelli, 1996). $\sigma^2 = \sigma^2_v + \sigma^2_u$. This indicates total variance is due to variance in error term (v) and non-negative random variable (u), where in v and u assumed to be independent of each other. The error term v_i represents the influence of factors outside the control of the farmer, while u_i represents the cost inefficiency factors because of poor management practices which are under control of the farmer. This variance parameter in model is represented by Gamma value, calculated using the following equation:

$$\gamma = \frac{\sigma^2_u}{\sigma^2_v + \sigma^2_u}$$

Factors Affecting the Cost inEfficiency

In order to assess the factors associated with cost inefficiency, the cost efficiency scores were used. It was analysed taking the degree of cost efficiency scores as dependent variable. The empirical specification of the cost inefficiency model is given by (Bettese and Coelli, 1995).

$$u_i = \delta_0 + \sum_{m=1}^{7} (\delta_m Z_m)$$

Where Z_{mi} are socio-economic characteristics, Z_{1i} is age of the farmer. Z_{2i} is education (0 = Illiterate, 1 = primary, 2 = secondary, 3 = college, 4 = graduation), Z_{3i} is landholding of the farmer, Z_{4i} is the size of the family, Z_{5i} is the experience in farming, Z_{6i} is a binary variable equal to one if the farmer has membership in any organization and zero otherwise and Z_{7i} is binary variable equal to one if the farmer has access to extension services and to zero otherwise.

Results and Discussion

Socio-Economic Characteristics of Rice Farmers

The socio-economic characteristics of the farmers is given in Table 1. The results indicated that average age of the farmers under conventional rice cultivation was 53 years and with respect to SRI, aerobic and DSR farmers, the average age was 48, 47 and 43 years, respectively. The average landholding was more than

Table 1

Socio-economic characteristics of rice farmers under different rice cultivation system

Variables	Conventional (n=30)	SRI (n=30)	Aerobic (n=30)	DSR (n=30)
Age (years)	53.00	48.00	47.00	43.00
Education level (years of formal education)	8.00	8.00	10.00	10.00
Landholding (acres)	4.83	3.08	3.33	3.40
Experience (years)	25.00	22.00	20.00	20.00
Family size (No.)	5.00	5.00	5.00	5.00
Membership (No.)	13.00 (43)	21.00 (70)	19.00 (63)	20.00 (67)
Access to extension services (No.)	6.00 (20)	25.00 (83)	23.00 (77)	27.00 (93)

Note: Figures in parentheses indicate percentage to total

3 acres for SRI, aerobic and DSR farmers but was more than 4 acres for farmers under conventional rice cultivation. The conventional farmers had around 8 years of formal education and SRI, aerobic and DSR farmers had 8, 10 and 10 years of formal education, respectively. The farmers under all the cultivation system had more than 20 years of experience in farming. It was also found that majority of the farmers belonged to the family size of five across all the systems.

It was noticed that around 43 per cent of the farmers under conventional rice cultivation had membership in organizations and 70, 63 and 67 per cent of the farmers under SRI, aerobic and DSR cultivation had membership in organizations, respectively. It was also noted that more than 70 per cent of the farmers under SRI, aerobic and DSR had access to extension services but it was only 20 per cent for farmers under conventional method.

Table 2

Maximum likelihood estimates of the stochastic cost frontier of rice farmers (Conventional method)

Variables	Coefficients	t-ratio
Constant	- 9.309	-1.024
Seed cost	1.048 *	2.576
Fertilizer cost	-0.082	-0.335
Human labour cost	1.960 **	2.127
Machine labour cost	0.914 *	2.830
Inefficiency model		
Constant	1.597	0.624
Age	0.239 *	2.902
Education	0.144	0.878
Land holding	-0.022 **	- 2.074
Family size	-0.280	-0.734
Experience in farming	0.215 *	3.741
Membership in organization	-1.006	-0.270
Access to extension services	-0.359	-0.860
Variance parameters		
Sigma squared	0.221 *	3.867
Gamma	0.437 **	2.292
Log likelihood	19.989	
LR statistic	14.054	

Note: *, ** indicates significance at one and five per cent probability level, respectively

Analysis of Cost Efficiency

The Cobb-Douglas cost function was estimated using the computer version FRONTIER 4.1 and the results of the maximum likelihood estimates of the stochastic cost frontier of rice farmers under conventional rice cultivation is given in Table 2. The results revealed that one per cent increase in the seed cost, human labour and machine labour cost will increase the total cost by 1.05, 1.96 and 0.9 per cent, respectively and was found significant. The estimated coefficient of the explanatory variables in the cost inefficiency model shows that all the coefficients have the expected signs except age and experience. With increase in age and experience by one per cent the cost inefficiency increased by 0.239 and 0.215 per cent indicating that the farmers who are old are reluctant to adopt the cost efficient technologies. This is in line with the findings of Singh *et al.* (2020) who reported that age is positively related to cost inefficiency. Similarly with respect to increase in experience, following conventional practices leads to increased cost inefficiency.

Sigma squared (σ^2) on the other hand is 0.221 and statistically significant at one per cent indicating correctness of fit of the model as assumed for the composite error term. The estimated gamma parameter of 0.437 is highly significant at five per cent, indicating that around 44 per cent of the variation in the total cost of production among the sampled farmers is due to differences in their cost efficiency. Moreover, the presence of cost inefficiency was tested by LR (Likelihood Ratio) statistic, it was 14.054 which is lesser than the critical chi square value of 24.049, which implies the assumption of no cost inefficiency was rejected.

TABLE 3

Maximum likelihood estimates of the stochastic cost frontier of rice farmers (SRI method)

Variables	Coefficients	t-ratio
Constant	2.452 *	3.501
Seed cost	0.054 *	5.977
Fertilizer cost	0.130 *	13.877
Human labour cost	0.340 *	12.923
Machine labour cost	0.373 *	9.033
Inefficiency model		
Constant	-0.106	-0.199
Age	0.009	0.158
Education	-0.078	-1.429
Land holding	-0.039	-0.279
Family size	-0.023	-0.828
Experience in farming	- 0.011	-0.427
Membership in organization	-0.075 **	-2.389
Access to extension services	-0.289 *	-2.595
Variance parameters		
Sigma squared	0.636 *	3.733
Gamma	0.719 *	3.433
Log likelihood	70.878	
LR statistic	20.539	

Note : *, ** indicates significance at one and five per cent probability level, respectively

TABLE 4

Maximum likelihood estimates of the stochastic cost frontier of rice farmers (Aerobic method)

Variables	Coefficients	t-ratio
Constant	12.955 *	11.533
Seed cost	0.056 *	4.510
Fertilizer cost	0.140 *	5.540
Human labour cost	0.426 *	9.329
Machine labour cost	0.598 *	5.213
Inefficiency model		
Constant	-0.115	-0.167
Age	0.074	0.339
Education	-0.310 *	-2.77
Land holding	-0.002	-0.078
Family size	-0.048	-0.689
Experience in farming	0.060	1.940
Membership in organization	-0.039	-1.120
Access to extension services	-0.017	-1.130
Variance parameters		
Sigma squared	0.031 *	3.763
Gamma	0.89 *	190.080
Log likelihood	68.58	
LR statistic	23.346	

Note : *, ** indicates significance at one and five per cent probability level, respectively

The maximum likelihood estimates of the stochastic cost frontier of rice farmers under SRI method of rice cultivation is given in Table 3. The cost elasticities of all the input variables used in the cost analysis were positive which implies that an increase in the cost of seed, fertlilizer, human labour and machine labour increases total production costs. The coefficients were positive and significant at one per cent. One per cent increase in costs of seed, fertlilizer, human labour and machine labour increases the cost by 0.054, 0.130, 0.340 and 0.373 per cent, respectively.

The inefficiency effects of membership in organization and access to extension services was negative and significant. This means that both the factors are contributing positively to cost efficiency. The farmers obtain required and necessary technical advice and knowledge, thereby produce at efficient costs. Increase in membership in organization and access to extension services by one per cent would lead to increase in cost efficiency by 0.075 and 0.289 per cent, respectively.

The sigma squared value was 0.636 and significant at one per cent level indicating the goodness of fit. The gamma parameter was estimated to be 0.719 and was significant at one per cent level. This reveals that approximately 72 per cent of the variation in the total cost of production among the sampled farmers is due to differences in their cost efficiency. LR statistic was 20.539 and lesser than the critical chi square value of 24.049, depicting the presence of cost inefficiency.

The result of stochastic cost frontier for aerobic rice cultivation is depicted in Table 4. It was observed that coefficients of all the input variables *i.e.* cost of seeds, fertilizers, human labour and machine labour were highly significant at one per cent level. With respect to inefficiency effects, education was found negative and significant at one per cent level. Increase in education by one per cent decreases cost inefficiency by 0.37 per cent. This reveals that higher the level of education, higher the cost efficiency of the farms. Aboaba (2020) reported that higher the level of education, the higher the allocative efficiency, which implies that educated farmers are allocatively efficient compared to their counterparts. The Sigma squared estimate (0.031) was also significant at one per cent level indicating the good fit of the model. The gamma value was 0.89 which revealed that 89 per cent of the variation in cost of production is attributed to the variation in costs among the rice farmers and is due to differences in cost efficiency.

TABLE 5

Maximum likelihood estimates of the stochastic cost frontier of rice farmers (DSR method)

Variables	Coefficients	t-ratio
Constant	7.634 *	7.931
Seed cost	-0.005 *	-3.005
Fertilizer cost	0.109	0.103
Human labour cost	0.169 *	3.085
Machine labour cost	0.022 **	2.045
Inefficiency model		
Constant	0.006	0.007
Age	0.003	0.004
Education	-0.200 *	-3.019
Land holding	-0.024	-0.092
Family size	-0.002	-0.012
Experience in farming	-0.022	-1.302
Membership in organization	-0.036	-0.113
Access to extension services	-0.083 *	55.770
Variance parameters		
Sigma squared	0.092 **	1.908
Gamma	0.69 **	2.502
Log likelihood	29.104	
LR statistic	7.528	

Note: *, ** indicates significance at one and five per cent probability level, respectively

It was observed from the stochastic cost frontier analysis under DSR rice cultivation that the cost of human labour was significant at one per cent whereas seeds and machine labour was significant at five per cent level. The coefficients obtained for the maximum likelihood estimates are given in Table 5. Even in the case of DSR method, increase in all the input variables increases the total cost. In the case of cost inefficiency effects, access to extension services and education were significant and one per cent increase in education and extension services decreases cost inefficiency by 0.20 and 0.08 per cent, respectively. Sigma squared and gamma was observed to be 0.092 and 0.69 and was significant at five per cent level.

Efficiency Distribution of Rice Farmers Under Different rice Cultivation Systems

The distribution of farmers according to the cost efficiency scores is presented in Table 6. It was observed that mean efficiency score was 0.55, 0.92, 0.94 and 0.88 for conventional, SRI, aerobic and DSR cultivation, respectively. This indicates that the cost efficiency was highest in aerobic rice cultivation. The cost efficiency obtained is supported by Aboaba (2020) which reported that mean allocative efficiency implies that rice farmers were 94 per cent cost-efficient, that is they were able to maximize their total output by minimizing 94 per cent of their total production cost, which shows that there is room for six per cent improvement.

Table 6

Distribution and summary statistics for cost efficiency scores of farmers under different rice cultivation systems

Cost efficiency scores	Conventional	SRI	Aerobic	DSR
≤0.5	9.00	-	-	-
>0.50 ≤0.70	20.00	4.00	-	7.00
>0.70 ≤0.90	1.00	4.00	2.00	3.00
>0.90	-	22.00	28.00	20.00
Mean	0.55	0.92	0.94	0.88
Minimum	0.12	0.60	0.86	0.66
Maximum	0.60	0.97	0.98	0.95

The lowest cost efficiency was obtained under conventional rice cultivation indicating that around 55 per cent of the farmers were allocatively efficient. The mean efficiency scores obtained for SRI method of cultivation was higher than 83 per cent as reported by Mwatete *et al.* (2015). With respect to DSR rice cultivation, the efficiency scores obtained are in line with results of Maurice *et al.* (2015) which reported allocative efficiency of 0.84 for food crop production among small scale farmers. Thus, there was 45 per cent room for increasing efficiency for conventional farmers and only 2 per cent for aerobic farmers.

The adoption of a rice cultivation system which decreases cost inefficiency is the important aspect in the present context because with rice being a major staple food it has to be seen that there is sufficient and sustainable rice production in the country which can be produced at minimum costs. The results from the maximum likelihood estimates revealed that cost of seeds, fertilizers, human labour and machine labour were the various input variables influencing cost of production. The variables such as age, landholding and experience in farming significantly influenced cost inefficiency in conventional rice cultivation. Membership in organization and access to extension services were significant in explaining cost inefficiency of SRI method of cultivation. The major factor for aerobic farmers was education which contributed significantly to cost efficiency. With respect to DSR method, age and access to extension services were the significant factors. Moreover, it was observed that the most cost efficient system was aerobic rice cultivation followed by SRI method and the system which had more scope for allocative efficiency was conventional method. Therefore, adopting aerobic rice cultivation or SRI method on a larger scale in the study area would help in increasing efficiency and sustainable management of resources.

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