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Cultivating Efficiency: An In-depth Analysis of Technical Efficiency in Kerala's Organic Vegetable Farming

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ABSTRACT

Background: The transition to organic farming in Kerala, motivated by environmental and health concerns associated with chemical-intensive agriculture, encounters challenges related to productivity and resource efficiency during the conversion phase. Despite policy initiatives, the technical efficiency of organic vegetable farming remains insufficiently explored, impeding evidence-based interventions. This study examines the technical efficiency of organic vegetable farmers in northern Kerala and identifies determinants to inform strategies for enhancing sustainability and profitability.

Methods: Primary data from 361 certified organic vegetable farmers were analyzed using a stochastic production frontier model with a truncated normal distribution. The Cobb-Douglas production function evaluated inputs (land, labor, capital, organic manure) and socio-economic factors (age, education, experience). Technical inefficiency effects were modeled via a one-step maximum likelihood approach.

Result: Farmers operated at an average technical efficiency of 21.4%, indicating significant underutilization of resources. Key determinants included experience (reducing inefficiency) and age (increasing inefficiency). Organic manure and land size positively impacted output, while education improved efficiency among full-time farmers. Over 75% of farmers required more than a 70% improvement to achieve full efficiency. The findings underscore the necessity for targeted training, enhanced access to organic inputs and institutional support to optimize resource use and sustain Kerala's organic transition.

Key words: Frontier estimation, Organic vegetable farming, SDG 4, Technical efficiency.

JEL classification: C34, Q01, Q18.

INTRODUCTION

Increasing concerns regarding the environmental and health impacts of chemical-intensive agriculture drive the global transition towards organic farming. While the Green Revolution significantly enhanced food security (Das, 2007), its long-term consequences-including soil degradation, biodiversity loss and water contamination-have raised critical sustainability concerns (Isenring, 2010; Pimentel *et al.,* 2005). Organic farming, with its emphasis on natural soil management and biodiversity conservation, presents a promising alternative to mitigate these challenges (McCann *et al.,* 1997; Verma *et al.,* 2015). A central debate in global agricultural discourse revolves around whether organic farming can meet the food demands of a growing population. Critics argue that conventional farming is indispensable for feeding the projected 9 billion people by 2050 (Borlaug, 2002; Connor, 2008). Conversely, proponents suggest that organic agriculture can enhance food security while restoring environmental and human health (Badgley *et al.,* 2007; Halweil, 2006). Evidence suggests that after an initial yield decline, organic farming can match or surpass conventional yields (Liebhardt *et al.,* 1989; Rajendran *et al.,* 2000).

As the 20th century drew to a close, the average Indian citizen became increasingly aware of the negative consequences associated with chemical-intensive agriculture (Singh *et al.,* 2022). However, its adoption is impeded by factors such as yield instability, high certification costs and inadequate institutional support, particularly during the transitional phase (Liebhardt *et al.,* 1989; Reddy, 2010). By integrating organic resources with high-yielding varieties and advanced technologies, the country improved food production while addressing environmental pollution, pesticide toxicity and agricultural sustainability (Gugalia, 2021). The National Programme for Organic Production (NPOP), launched in 2001, played a key role in promoting organic farming, making India the global leader in organic producers (FiBL Survey Report, 2019). However, challenges such as limited market access, low awareness and inadequate research persist (Reddy, 2010). Policy

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discussions emphasize the need for region-specific strategies and improved market infrastructure (NAAS, 2005). In response, eleven state governments introduced organic farming policies, with Kerala being an early adopter (Murry, 2019).

Kerala's 2008 Organic Farming Policy aimed for full transition within five years, targeting 20% annual land conversion. The excessive use of chemical inputs had degraded soil health and posed health risks, exemplified by the endosulfan tragedy in Kasaragod, prompting stricter regulations. Concerns over food safety grew due to reports of pesticide residues in vegetables imported from Tamil Nadu (Palackal, 2019). Despite an overall decline in pesticide use, challenges like banned chemical usage and poor handling persist due to inadequate training (Devi, 2010).

Kerala's ban on 14 hazardous pesticides had no adverse impact on crop yields, proving the feasibility of organic farming (Sethi *et al.,* 2022). In response, the state launched the Jaiva Keralam initiative to revitalize agriculture and ensure toxin-free food. There is evidence of an increase in the production of yields in organic farming compared to chemical farming methods in Kerala. The practice of green manuring in Cassava improved its growth and yield (Suja *et al.,* 2020). On-farm trials with organic inputs showed a 21% higher yield and 38% greater profit than conventional farming, supporting organic practices for better yield, profit and soil health in non-trailing white yam (Suja *et al.,* 2020).

Despite the government's initiatives to transition Kerala into a fully organic farming state, concerns regarding the sustainability of agricultural yields and resource efficiency persist. Various interventions, including the promotion of women's self-help groups, household and terrace farming and seed distribution through Krishibhavans, have been implemented to support this transition. However, the productivity and efficiency of organic vegetable farming remain uncertain. While extant research has examined aspects such as market access, policy interventions and environmental benefits, there is a significant lacuna in understanding the technical efficiency of organic vegetable cultivation. The extent to which resources are optimally utilized, the potential for increased output and the key determinants of efficiency remain unexplored. This knowledge gap impedes the formulation of evidence-based policies necessary for enhancing farm productivity and ensuring the long-term viability of organic agriculture.

In this context, the present study aims to analyze the technical efficiency of organic vegetable farming in northern Kerala, identify the factors influencing efficiency and provide insights to inform policy interventions. The findings are expected to contribute to the development of targeted strategies that enhance productivity, support farmers and facilitate a more effective transition toward sustainable organic farming practices.

MATERIALS AND METHODS

This study employs a primary data collection approach to estimate the technical efficiency of organic vegetable farmers. The study was conducted at the Central University of Tamil Nadu. Data were gathered through a structured household survey conducted among certified organic vegetable farmers in Kerala. Before the main survey, a pilot study was undertaken to assess the questionnaire's effectiveness and necessary modifications were implemented based on expert consultations and farmer interactions. To ensure reliability, Cronbach's Alpha test was applied, yielding an alpha value of 0.61, indicating acceptable internal consistency. Kerala is divided into three historical regions: Northern, Central and Southern Kerala. This study focuses on the northern districts where organic farming has gained significant traction.

The study area was selected based on preliminary field observations and expert recommendations. The target population consists of farmers adhering to Good agricultural practices (GAP) certification. The selection criteria for respondents included:

(i) Holding GAP certification,

(ii) Cultivating vegetables on a minimum land area of 10 cents.

(iii) Completing the transitional period to organic farming.

Utilizing official records from respective Krishi Bhavans and the Principal Agricultural Officer (PAO), a total of 5,946 organic vegetable farmers were identified. The sample size was determined using Cochran's formula, resulting in a selection of 361 farmers. Data on socio-economic characteristics, production practices, financial aspects, fertilization and farm groups were collected through structured survey schedules.

Theoretical methodology: Stochastic frontier approach

Theoretical Methodology: Stochastic Frontier Approach this study utilizes the Stochastic Frontier Analysis (SFA) to assess the technical efficiency of organic farmers, incorporating both inefficiency and statistical noise. The Maximum Likelihood method with a truncated-normal distribution is employed, providing greater efficiency than COLS (Richmond, 1974; Coelli, 1996). A one-step approach is adopted to model inefficiency as a function of farm-specific factors, thereby addressing biases inherent in the two-step method (Kumbhakar and Hjalmarsson, 1991; Huang and Liu, 1994). The Cobb-douglas production function is applied and a likelihood-ratio test confirms the presence of one-sided error.

Empirical model

The Cobb-Douglas functional form has been utilized to determine the frontier production of organic vegetable farmers. The variables that have been identified to determine frontier production are total production, land, labor, fertilizer and capital. To capture the technical inefficiency effects in a single step, the normal distributional form has been employed. The socio-economic variables of age, education, experience in farming, occupation of the farmer and membership in farming groups have been identified to estimate the technical inefficiency. In this study,

the first three variables (age, experience and education) are included in the estimation of technical inefficiency model, while the other three variables are used to categorize farmers into different groups, such as full-time farmers, farmers with other jobs based on their occupation, farmers who are members of farming groups and farmers who are not members of farming groups. This categorization is intended to understand the percentage difference in technical efficiency with the influence of the variables on technical efficiency. Therefore, the study includes age, education and experience as exogenous variables to measure the technical inefficiency of organic farmers (Palathingal, 2019). The empirical model used in estimating the level of technical efficiency specifies as:

$$\ln Yi = \beta_0+\beta_1 \ln X_1+\beta_2 \ln X_2+\beta_3 \ln X_3+\beta_4 \ln X_4+V_i-U_i \quad ...(1)$$

Where,

ln = Natural logarithm.

Y_i = Total production.

X_1 = Land.

X_2 = Labor.

X_3 = Capital.

X_4 = Organic manure.

β_1 - β_4 = Parameters estimated.

V_i = Systematic error accounting for the effect of random variation in output due to factors beyond the control of the farmers.

U_i = Non-negative random variable representing inefficiency associated with technical inefficiency in production.

To assess the elements that influence the technical efficiency observed in organic vegetable cultivation, we formulated and estimated two equations in conjunction with equation 1, utilizing a one-step maximum likelihood estimation methodology.

$$U_i = \delta_0+ \delta_1 Z_1 +\delta_2 Z_2+\delta_3 Z_3 \quad ...(2)$$

Where,

U_i = Technical inefficiency of the i^{th} farmer.

δ_0 = Constant.

δ_1 to δ_3 = Unknown parameters.

Z_1 = Age of the farmer.

Z_2 = Experience of the farmer.

Z_3 = Education of the farmer.

The stochastic production frontier model, which is utilized in this study to estimate the determinants of technical efficiency, is the sole factor that varies based on sample size across each model. In order to determine the choice of frontier production function and test the null hypothesis, the generalized likelihood ratio test was conducted.

RESULTS AND DISCUSSION

The results of the maximum likelihood estimator of the Cobb-douglas stochastic production frontier and technical inefficiency effect model for different organic vegetable farmers groups are presented in Table 1. In the stochastic production frontier model, the farmer's frontier production is the dependent variable. Maximum likelihood techniques are used to estimate the production function parameters β. In Section 2, the technical inefficiency (MU) is the dependent variable and the normal distribution is used to estimate the technical inefficiency parameters ζ, using β computed.

The first model, examining total organic vegetable farmers, labor, land and organic manure, shows these variables have a significant positive relationship with frontier output at the 1% level. This aligns with studies by Songsrirote and Singhapreecha (2007) and Issaka *et al.* (2016). Capital is not significant in this model. Organic manure significantly impacts technical efficiency, with a one-unit increase leading to a 0.4693 unit increase in frontier production (Palathingal, 2019). Shinde and Hunje (2019) also found organic manure improved seed quality. The constant is significant in this model. In the technical inefficiency model, age and experience are significant at 5%, while education is not. The positive coefficient for age suggests inefficiency increases with age, aligning with Tzouvelekas *et al.* (2001). The negative coefficient for experience indicates more experienced farmers are more efficient, corroborating Lohr and Park (2006) and Nwaru and Ndukwu (2012).

Farmers are divided into two groups based on land size: more than two acres and less than two acres. Both groups show significance at 1%. For large-scale farmers, organic manure and land are significant at 10% and 1%, respectively. For small-scale farmers, all variables are significant at 1%, with capital having the greatest impact. Technical inefficiency variables age and experience are significant for large-scale farmers, with age positively related to inefficiency and experience negatively, the results align with the findings of Nastis *et al.* (2012). For small-scale farmers, no inefficiency variables are significant. The study also categorized farmers by occupation: full-time (196) and part-time (104). Both models show significance at 1%.

For full-time farmers, land, organic manure and labor are significant at 1%, while capital is not. For part-time farmers, organic manure and capital are important at 1% and 10%, respectively. In the technical inefficiency model, education is key for full-time farmers, reducing inefficiency by 0.0513 units per year of schooling. Age and experience are not significant for full-time farmers. For part-time farmers, only age is significant at 5% and positively affects technical efficiency.

Being a member of a farming group can provide farmers with access to information about innovative techniques, policies and subsidies. Both models are statistically significant at the 1% level. The study reveals that land, labor and organic manure are statistically significant at 1% for both groups, while capital is only significant for farmers in a farming group. Capital contributes significantly to the frontier production of group members, while organic manure impacts frontier production of non-members. In the technical inefficiency model, experience is significant at 5% in the member group model, indicating a positive relationship with technical efficiency. No other variables are significant in the non-

Table 1: ML estimates and technical inefficiency.

		Total organic vegetable farmers	Large scale farmer	Small scale farmer	Full-time farmer	Other jobs	Member in farm group	Not a member
Frontier	Ln land	.29113***	0.3991***	.29835***	0.4460***	-.0101	0.2272***	0.4110***
		(0.0723)	(0.969)	(0.000)	(0.0830)	(0.1225)	(0.0073)	(0.1050)
	Ln organic	46934***	.6607*	.30630***	0.4414***	0.5196***	0.4394***	0.4392***
	manure	.(0.0717)	(0.2578)	(0.000)	(0.0943)	(0.1259)	(0.124)	(0.1024)
	Ln labor	.25518***	-.0750	.3170***	0.2629***	0.1757	0.1875***	0.2972***
		(0.0525)	(0.0668)	(0.000)	(0.0624)	(0.1183)	(0.0378)	(0.0755)
	Ln capital	.19107	-.0556	.6090***	0.1895	0.4095*	0.5169***	0.0358
		(0.1174)	(0.1602)	(0.000)	(0.1509)	(0.0863)	(0.1081)	(0.1920)
	-cons	2.634*	6.4684***	-.8516***	2.7171**	0.8041	0.1166	3.8697**
		(1.1013)	(0.3139)	(0.001)	(1.177)	(1.2636)	(0.4755)	(1.5845)
Mu	Age	0.114*	0.0414*	.0085	0.0067	0.0170**	0.0136	0.0122
		(0.0054)	(0.01807)	(0.007)	(0.0074)	(0.0085)	(0.0093)	(0.0077)
	Education	-0.0200	-0.0331	-.0150	-0.0513**	-0.001	-0.0317	-0.0101
		(0.0143)	(0.0390)	(0.019)	(0.02575)	(0.0202)	(0.0213)	(0.024)
	Experience	-0.0117*	-0.0573**	-0.0044	-0.0125	-0.004	-0.0215**	-0.0021
		(0.0060)	(0.0183)	(0.007)	(0.0076)	(0.0106)	(0.0090)	(0.0104)
	-cons	1.4747*	0.5163	1.1146**	1.7738**	0.907	1.2902**	1.1047
		(0.5880)	(1.0158)	(0.441)	(0.6244)	(0.5936)	(0.5454)	(0.8879)
Usigma	-cons	-0.2396	0.2028	0.0771	-0.2001	-0.235	0.0287	-0.3137
		(0.1849)	(0.2811)	(0.136)	(0.2127)	(0.2013)	(0.1727)	(0.3862)
Vsigma	-cons	-2.2465	-31.732	-32.321	-2.314*	-28.62	-31.389	-1.7933
		(1.2011)	(281.62)	(194.04)	(1.3073)	(187.73)	(245.364)	(1.3624)
Sigma_u		.8870***	1.1067***	1.039***	0.9047***	0.8891***	0.8547***	1.0144***
		(0.0820)	(0.1555)	(0.0708)	(0.0962)	(0.089)	(0.0876)	(0.1651)
Sigma_v		.3252	1.29	0.000	0.3143	0.0000	0.4079***	5280
		(0.1953)	(0.000)	(0.000)	(0.2054)	(0.000)	(0.000)	(0.2778)
Lambda		2.727***	86030***	10800***	2.878***	14620***	2.0955***	6644***
		(0.2564)	(0.1555)	(0.0708)	(0.2720)	(0.08951)	(0.08761)	(0.4189)

Source: Author calculations.

Table 2: Distribution of farmers according to technical efficiency indices.

The range of technical efficiency indices	Total production		Land size				Occupation				Member in farm group			
			Large		Small		Full time farmer		Other jobs		Member		Not a member	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
0 to 10	77	25.7	16	27.6	47	19.4	42	21.4	28	26.9	32	20.9	32	21.9
10.1 to 20	104	34.7	16	27.6	74	30.6	64	32.7	38	36.4	49	32	43	29.5
20.1 to 30	47	15.7	9	15.5	37	15.3	39	19.9	14	13.5	23	15	33	22.6
30.1 to 40	30	10	4	6.9	23	9.5	20	10.2	8	7.7	12	7.8	14	9.6
40.1 to 50	18	6	4	6.9	17	7	8	4.1	6	5.8	11	7.2	13	8.9
50.1 to 60	14	4.7	1	1.7	13	5.4	14	7.1	1	1	8	5.2	7	4.8
60.1 to 70	6	2	1	1.7	11	4.5	5	2.6	3	2.9	4	2.6	2	1.4
70.1 to 80	2	0.7	0	0	6	2.5	3	1.5	3	2.9	4	2.6	2	1.4
80.1 to 90	2	0.7	2	3.4	6	2.5	1	0.5	0	0	3	2	0	0
90.1 to 99	0	0	1	1.7	2	0.8	0	0	1	1	3	2	0	0
99.1 to 100	0	0	4	6.9	6	2.5	0	0	2	1.9	4	2.6	0	0
Total	300	100	58	100	242	100	196	100	104	100	153	100	147	100
Maximum	82.78		99.9		99.9		85.61		99.9		99.9		79.071	
Mean	21.4		28.46		28.78		23.35		23.19		28.18		22.82	
Minimum	1.1		1.6		24.08		1.46		0.89		0.76		2	

Source: Author calculations.

member group. A study of (Parvathi and Waibel, 2016) found that joint farming has a significant impact on income from organic farming compared to conventional black pepper farming. After determining the appropriate model, the average technical efficiency for each group and individual farmer was calculated. The distribution of individual technical efficiency of organic vegetable farmers is summarized in the table. The estimated mean technical efficiency is 21.4%, indicating significant inefficiencies in production and potential for improvement. To achieve full efficiency, farmers need to increase output by 78.6%. The highest technical efficiency observed is 82.78%, indicating an inefficiency of 17.22%. The least efficient farmer requires a 78.6% improvement. Approximately half of the farmers (57.7%) are highly inefficient, utilizing less than 50% of their total capacity. Most farmers are not optimizing their resource use to achieve full efficiency.

Table 2 presents the distribution of farmers according to their technical efficiency indices. This distribution facilitates a comparative analysis of the technical efficiency levels among different groups of farmers. Furthermore, it provides insights into whether specific group characteristics have a significant influence on their technical efficiency. The comparison based on farm size shows little difference in technical efficiency between large-scale (28.46%) and small-scale (28.78%) farmers, with both groups being highly inefficient. Large-scale farmers can improve output by 71.54% and small-scale farmers by 72.22%, to reach full efficiency. This finding contradicts the results of Rajendran *et al.* (2015), who reported that larger farms tend to be more efficient. Similarly, a study by Ngo *et al.* (2025) found a positive correlation between farm size and technical efficiency. However, the current study did not support these conclusions. Instead, the findings align with Sharma, Dutta and Singh (2024), who reported a neutral relationship between land size and productivity. Overall, both farm sizes exhibit significant potential for efficiency improvement.

Comparisons based on occupation reveal that full-time farmers (23.35% efficiency) and part-time farmers (23.19% efficiency) have similar levels of technical efficiency. Both groups are highly inefficient, needing improvements of 76.65% and 76.81%, respectively, to achieve full efficiency. This suggests that part-time farmers can match the efficiency of full-time farmers despite their divided focus. Both groups have substantial room for efficiency enhancement.

Membership in farming groups provides a slight efficiency advantage, with members having a mean efficiency of 28.18% compared to 22.82% for non-members. However, 82.9% of group members and 92.5% of non-members are below 50% efficiency. Both groups are highly inefficient, requiring improvements of 71.82% and 77.18%, respectively, to reach full efficiency. Despite the small efficiency gain, both member and non-member farmers have significant potential for improvement. Table 2 depicts the cumulative technical efficiency distributions obtained the normal stochastic frontier model.

The study compares technical efficiency across seven farmer categories, revealing key findings. Land, labour, capital and organic manure positively impact frontier production in small-scale farmers, males and farm group members. Organic manure significantly boosts output in all models except small-scale, full-time and group members. Land is significant except for farmers with other jobs, while labor and capital are insignificant in large-scale and other job models, negatively impacting large-scale farmers. Education reduces inefficiency in full-time farmers and age increases inefficiency in total, large-scale, male and other job models. Experience decreases in inefficiency in all the farmer's groups. Membership, land size and occupation show minimal impact on overall efficiency. Overall, significant inefficiencies exist across all farmer groups, highlighting the need for targeted interventions to enhance technical efficiency.

CONCLUSION

This study underscores inefficiencies in organic vegetable farming across farmer groups in Kerala, highlighting scope for productivity enhancement. Findings indicate that land, labor and organic manure significantly contribute to frontier production, while education and farming experience mitigate technical inefficiency. Despite policy interventions, farmers face challenges in optimizing resource utilization, particularly concerning capital efficiency and land productivity. Variations in farm size and membership in farmer groups show limited influence on overall efficiency, suggesting broader structural and institutional constraints may impede performance improvements. Organic manure emerges as an important input, reinforcing the need for policies enhancing its accessibility and adoption. Despite organic farming's sustainability promise, inefficiencies persist due to knowledge gaps, resource limitations and structural barriers. Strengthening education, training and farmer group participation is essential for improving efficiency, alongside targeted institutional support. Addressing these inefficiencies is critical for Kerala's goal of becoming a fully organic state, ensuring sustainability and profitability. Future research should assess the long-term economic impact of organic farming, evaluate policy interventions and explore strategies for enhancing efficiency and sustainability in the organic farming sector.

Policy implications

To enhance the efficiency of organic vegetable farming in Kerala, policymakers must prioritize improving access to organic manure through financial incentives, cooperative networks and targeted awareness campaigns. Structured training programs, led by experienced organic farmers, can address knowledge gaps and promote best practices. Education plays a crucial role in improving technical efficiency, particularly in land and water conservation.

Capacity-building initiatives, skill-development workshops and accessible educational resources should be integrated into agricultural policies to support farmers in adopting modern organic techniques. Strengthening farmer groups, comprising a combination of experienced and educated members, can facilitate knowledge exchange and improve productivity. Additionally, the government should streamline organic certification processes and improve market access to enhance farmers' profitability. While Kerala has made progress, achieving a fully organic state requires a comprehensive policy approach that integrates education, resource accessibility, farmer collaboration and institutional support, ensuring both sustainability and profitability in the long term.

Conflict of interest

The authors affirm that there are no conflicts of interest pertaining to the publication of this manuscript. All authors have made significant contributions to the research and preparation of the manuscript and have approved the final version. No financial, personal, or professional relation-ships have influenced the work reported in this study.

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