

Efficiency of shower and sprinkler irrigation system on curly red chili in coastal area Kulon Progo, Indonesia, using a stochastic frontier approach

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²Department of Civil Engineering, Faculty of Engineering, Universitas Muhammadiyah Yogyakarta. Jl. Brawijaya, Tamantirto, Kasihan, Bantul 55183, Yogyakarta, Indonesia

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Manuscript received: 6 December 2025. Revision accepted: 27 April 2026.

Abstract. Fivintari FR, Nurmalita, Ikhsan J, Mulyono, Ekawati FI, Yunanto, Ardila RA. 2026. Efficiency of shower and sprinkler irrigation system on curly red chili in coastal area Kulon Progo, Indonesia, using a stochastic frontier approach. *Asian J Agric* 10 (1): g100161. <https://doi.org/10.13057/asianjagric/g100161>. Coastal agriculture faces significant production challenges due to sandy soil characteristics, limited water retention, and increasing pressure on water resources. Improving irrigation efficiency is therefore essential to enhance productivity and sustainability in these environments. This study aims to evaluate the technical efficiency of curly red chili production under shower and sprinkler irrigation systems in the coastal area of Kulon Progo, Indonesia. The analysis employs a Cobb–Douglas production function estimated using the Stochastic Frontier Analysis (SFA) approach, which allows for the separation of random shocks and technical inefficiency in agricultural production. Both irrigation groups were technically efficient, with average technical efficiency levels above 0.7. However, sprinkler irrigation was more efficient than shower irrigation, with average scores of 0.902 and 0.795, respectively. Overall, the curly red chili farming business can achieve a maximum production of around 82.2% by using a combination of various production factors, suggesting that output could still be increased by approximately 17.8% through better input management and technology adoption without expanding resource use. The findings further demonstrate that irrigation technology plays a critical role in determining production efficiency. In particular, sprinkler irrigation is found to be more technically efficient than shower irrigation, reflecting its advantages in water distribution and labor use in sandy coastal conditions. These results highlight the importance of appropriate irrigation system selection as a key strategy for improving farm performance in coastal agriculture. The study provides empirical evidence to support the promotion of more efficient irrigation technologies and targeted extension programs aimed at enhancing technical efficiency. Overall, the findings contribute to the literature on irrigation efficiency in coastal farming systems and offer practical insights for farmers and policymakers seeking to improve productivity under challenging environmental conditions.

Keywords: Coastal farming, efficiency, irrigation, production, stochastic frontier

INTRODUCTION

Coastal agriculture plays an important role in supporting global food security, yet its development is constrained by several biophysical limitations, including high soil porosity, freshwater scarcity, and soil salinity (Islam et al. 2021; Suprayogi et al. 2022; Ghirardelli et al. 2025). In sandy coastal areas, the very low water-holding capacity and high infiltration rates reduce the effectiveness of conventional irrigation practices, making production efficiency a key factor for sustaining agricultural productivity under limited resource conditions (Huang and Hartemink 2020; Cao et al. 2021). In this context, Technical Efficiency (TE), defined as the ability of producers to achieve maximum output from a given set of inputs under existing technology, becomes highly relevant (Färe and Lovell 1978). Improving TE is important in developing countries, where increasing output through additional input use is often constrained, so productivity

gains must be achieved by reducing inefficiencies within the production process (Yohannis et al. 2020).

Water management through appropriate irrigation technology is therefore critical in coastal farming systems. Irrigation methods such as shower and sprinkler systems differ in their water distribution uniformity and ability to maintain soil moisture in highly porous soils, which directly affects crop performance (Rao et al. 2017; Singh and Singh 2020). This issue is especially relevant for red chili, one of Indonesia's leading horticultural commodities and an important source of farmer income and regional agricultural output. In Kulon Progo, a major coastal chili-producing area in Yogyakarta, chili production has continued to increase despite a decline in harvested areas, suggesting that production efficiency and irrigation technology play a more decisive role than land expansion. Given that coastal soils are generally marginal, characterized by coarse texture, elevated salinity, and limited freshwater availability, the choice of irrigation

technology becomes a major determinant of agricultural viability (Pittalis et al. 2016; Hossain and Li 2024). Suitable irrigation systems can improve water delivery to the root zone, reduce operational costs, enhance productivity, and minimize yield losses caused by salinity stress (Rodrigues et al. 2013; Narayanamoorthy et al. 2024). Thus, selecting irrigation technologies that match the specific constraints of coastal environments is essential for improving long-term profitability and resource-use efficiency (Angélica et al. 2023).

Despite the growing body of research on technical efficiency in horticultural farming, most existing studies have been conducted in inland or paddy-field settings, leaving coastal agricultural systems relatively overlooked. Recent works have examined how farmers manage inputs and improve productivity in red chili cultivation (Abate et al. 2019; Sinatria et al. 2022), while others have evaluated the broader potential of micro-irrigation technologies across different crops (Singh and Singh 2020; Narayanamoorthy et al. 2024). At the same time, studies focusing on coastal regions emphasize how salinity, limited freshwater, and sandy soil structures make water management more complex and highly consequential (Pittalis et al. 2016; Hossain and Li 2024). Yet very few investigations have attempted to connect these coastal challenges with empirical assessments of how specific irrigation systems, such as shower and sprinkler irrigation shape farmers' technical efficiency.

In Indonesia, the application of Stochastic Frontier Analysis (SFA) to assess irrigation-based efficiency differences in sandy coastal agriculture remains limited. Although SFA has been widely used to evaluate technical efficiency in agricultural production, most studies have focused on non-coastal areas, while coastal farming systems, particularly those on sandy soils and horticultural crops such as curly red chili, have received far less attention (Pittalis et al. 2016; Abate et al. 2019; Hossain and Li 2024). This study addresses that gap by providing empirical evidence on how different micro-irrigation systems, namely shower and sprinkler irrigation, influence production efficiency and technical inefficiency in curly red chili farming under Indonesia's coastal conditions,

thereby offering policy-relevant insights for irrigation and horticultural development (Singh and Singh 2020). More specifically, this study aims to identify the production factors affecting curly red chili output under shower and sprinkler irrigation systems in Kulon Progo, measure the level of technical efficiency under both systems, and analyze the factors contributing to technical inefficiency.

MATERIALS AND METHODS

Study area

This research was conducted in the coastal area of Kapanewon Galur, Kulon Progo District (Figure 1), which was purposively selected as the largest center of chili production on sandy coastal land in the region (BPS Kabupaten Kulon Progo 2025). Data were collected during the 2024 planting season, spanning from March to July 2024, which coincided with the dry season. During this period, farmers cultivated chili on sandy soils characterized by low nutrient content and high soil porosity, leading to rapid water percolation. To address nutrient deficiencies, farmers applied livestock manure during land preparation. Meanwhile, the high soil porosity was managed through the use of shower and sprinkler irrigation systems.

Shower irrigation is a water application system that utilizes a water pump connected directly to hoses equipped with shower nozzles at the outlet. This system is commonly used during the dry season due to the need to extract water from bore wells. Sprinkler irrigation, in contrast, is a mechanically operated irrigation system that applies water under pressure, allowing for more automated and controlled water distribution. In this system, water is applied above the soil surface in the form of fine droplets, resembling rainfall, by channeling pressurized water through PVC pipes fitted with small nozzle outlets. These nozzles operate automatically without manual direction toward the curly red chili plants. Sprinkler systems are designed to irrigate predefined areas automatically and are equipped with adjustable timers to regulate irrigation duration and frequency.

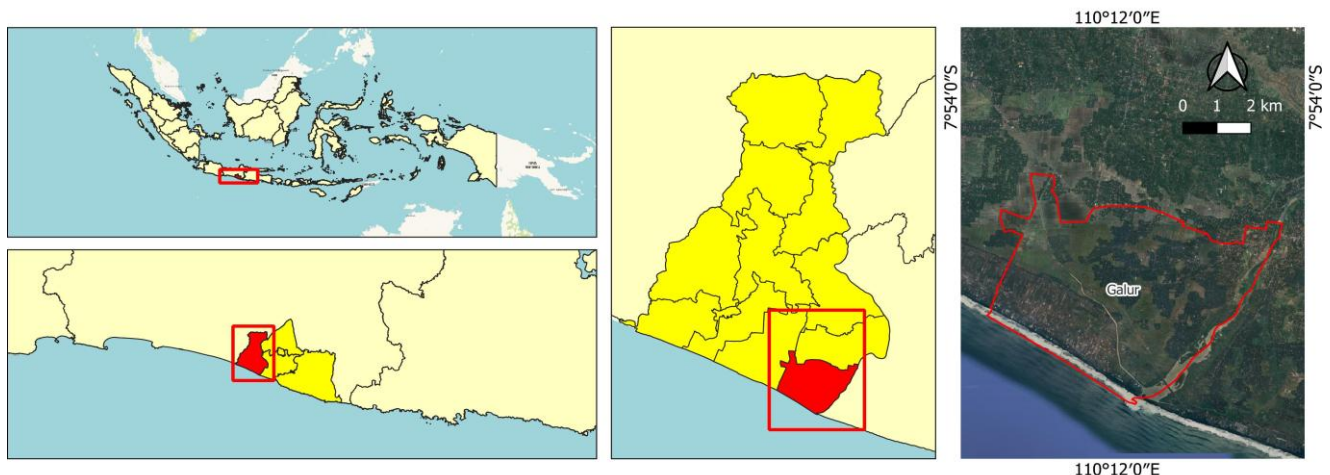


Figure 1. Location of the coastal area of Kapanewon Galur, Kulon Progo, Yogyakarta, Indonesia

Sampling procedure

A complete list of chili farmers registered in local farmer groups was used as the sampling frame. Farmers were then stratified based on their primary irrigation method (shower or sprinkler). The study was conducted using a census method, as the entire population of curly red chili farmers in the coastal area of Kapanewon Galur was included to ensure data representativeness. The total population of 110 farmers, consisting of 82 farmers using shower irrigation and 28 farmers using sprinkler irrigation was surveyed, effectively eliminating sampling error (Figure 2).

Data analysis

Cobb-Douglas production function with Stochastic Frontier Analysis (SFA) approach

The SFA model approach is considered to be the best analysis model where the calculation uses the frontier econometric method which creates a functional form of the relationship between costs, profits, or production between inputs, outputs, and other environmental factors. This allows for errors and inefficiency factors in measurements (Berger and Humphrey 1997). The stochastic frontier analysis model is estimated using the Maximum Likelihood Estimation (MLE) method with the main principle of maximizing the probability in estimating the estimated parameters. There are 14 independent variables used in the analysis of the production function of curly red chilies with shower and sprinkler irrigation systems in the coastal land of Kapanewon Galur with the following mathematical equation form:

$$\ln Y_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \beta_5 \ln X_{5i} + \beta_6 \ln X_{6i} + \beta_7 \ln X_{7i} + \beta_8 \ln X_{8i} + \beta_9 \ln X_{9i} + \beta_{10} \ln X_{10i} + \beta_{11} \ln X_{11i} + \beta_{12} \ln X_{12i} + \beta_{13} \ln X_{13i} + \beta_{14} \ln X_{14i} + v_i - u_i \quad [1]$$

Where, Y is the production of curly red chilies (kg), β_0 is a constant, β_i is the regression coefficient of the production factor or the parameter estimating the variable, X_{1i} is the land area (m²), X_{2i} is seed (gr), X_{3i} is NPK fertilizer (kg), X_{4i} is KCl fertilizer (kg), X_{5i} is fertilizer ZA (kg), X_{6i} is phonska fertilizer (kg), X_{7i} is KNO₃ fertilizzerred (kg), X_{8i} is manure (kg), X_{9i} is a liquid herbicide (ml), X_{10i} is a liquid insecticide (ml), X_{11i} is a liquid fungicide (ml), X_{12i} is a solid insecticide (gr), X_{13i} is a solid fungicide (gr), and X_{14i} is labor (man-day or workday), representing one person working for one day. As for V_i , it is an error that occurs due to factors beyond the control of farmers and factors causing technical inefficiency in curly red chili farming. The statistical significance of each estimated parameter was evaluated using t-statistics derived from the Maximum Likelihood Estimation (MLE) results. If the calculated t-value \geq t-table, then the i -th production factor (X_i) has a significant effect on curly red chili production (Y).

Technical efficiency

The technical efficiency level has a value of $0 \leq TE \leq 1$ where a value of 1 indicates that the farm is very technically efficient. Business will be technically efficient

if the technical efficiency index value is greater than or equal to 0.7, whereas if the technical efficiency index value is less than 0.7, the farm can be said to be inefficient (Battese and Coelli 1995). To calculate the technical efficiency index value, use the formula:

$$TE_i = \frac{Y_i}{\exp(X_i' \beta + v_i)} = \frac{\exp(X_i' \beta + v_i - u_i)}{\exp(X_i' \beta + v_i)} = \exp(-u_i) \quad [2]$$

Where, TE_i is the level of technical efficiency, Y_i is the actual farm output, Y_i^* is the potential output, V_i is the nuisance error outside the farmer's control (climate, weather, etc.), and $\exp(u_i)$ is the estimated frontier production obtained from the stochastic frontier production.

Technical inefficiency

Measuring technical efficiency using the stochastic frontier analysis method will reveal sources of technical inefficiency. These results can be used as a reference for improving farm inputs to increase technical efficiency. Mathematically, the formula for the technical inefficiency function is:

$$u_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + d_1 D_{1i} + d_2 D_{2i} \quad [3]$$

Where, u_i is the technical inefficiency value, δ_0 is a constant, Z_1 is the age of the farmer (years), Z_2 is the length of experience in cultivating curly red chilies (years), Z_3 is the level of farmer education (years), d_i is the estimated parameter coefficient, D_1 is the dummy type of irrigation (shower = 1 and sprinkler = 0), and D_2 is the dummy type of seed variety (jitu = 1 and laba = 0). The significance of each inefficiency determinant was assessed using t-statistics obtained from the MLE estimation results. If the calculated t-value \geq t-table, then the i -th internal factor (Z_i) has a significant effect on the inefficiency of curly red chili farming (u_i).

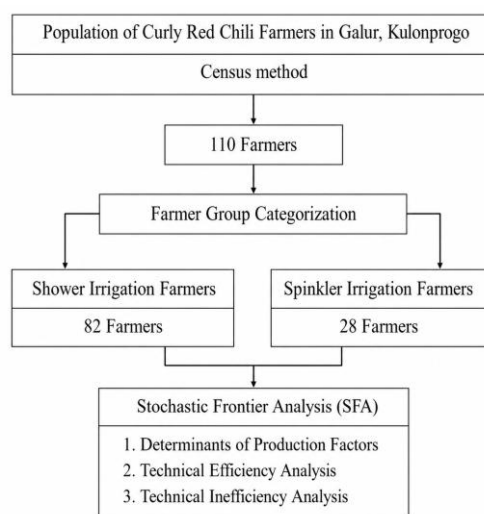


Figure 2. Research flowchart of sampling procedure and data analysis. Source: Created by author

RESULTS AND DISCUSSION

Stochastic frontier production function analysis

The estimated coefficients in the Cobb-Douglas production function can be interpreted as output elasticities of the respective inputs. The variables in this study were analyzed using a Cobb-Douglas production function with a Stochastic Frontier Analysis approach. The coefficient values for each variable can be used to determine how each variable affects red chili production. If an independent variable has a positive coefficient, then adding that variable will increase red chili production. Conversely, if the independent variable has a negative coefficient, adding that variable as a production factor will decrease production.

It is known that the results of the sigma-square estimation (σ^2) are greater than zero (>0) which is 0.026 and significant at the 95% confidence level. This indicates that the production of curly red chilies from farming activities in the coastal areas of Kapanewon Galur has real or significant variations. This means that there are cases of inefficiency in curly red chili farming in the coastal areas of Kapanewon Galur. The effect of technical inefficiency on the error value in the production function can be seen through the gamma (γ) value. A gamma value close to 1 indicates that many errors originate from technical inefficiency factors, while a gamma value close to 0 indicates that the error term is caused by external risk factors such as weather and climate. The results of the analysis show a gamma (γ) value of 0.870, which means that 87% of the error in farming production is caused by the effects of technical inefficiency and the remaining 13% is caused by risks or noise that are not controlled by farmers. The stochastic frontier estimation indicates that land area, KCl fertilizer, manure, liquid insecticide, and labor are the most influential factors affecting curly red chili production. Land area and labor show strong positive effects on output, while excessive use of manure and liquid insecticide significantly reduces production. In addition, the high gamma value suggests that most of the variation in production is explained by technical inefficiency rather than random external factors.

Production factors affecting curly red chili production

From the estimation results, there are 5 production factors that significantly influence the production of curly red chilies, namely land area, KCl fertilizer, manure, liquid insecticide, and labor. Based on Table 1, it can be seen that the constant is significant at the 99% confidence level and has a positive coefficient value (1.508). The constant term represents the intercept of the model and does not have a direct economic interpretation. In this logarithmic model, the constant represents the intercept of the production frontier, reflecting the base level of production determined by the state of technology and environmental factors not explicitly captured as independent variables in the model.

The independent variable of land area has a significant influence on the production of curly red chilies at the 99% confidence level. The coefficient of land area (0.8) indicates that a 1% increase in land area leads to an increase in output by 0.8%, *ceteris paribus*, reflecting its

elasticity with respect to production, assuming other inputs remain constant.

The KCl fertilizer variable shows a positive coefficient of 0.005 at a 99% partial confidence level. This means that every 1% addition of KCl fertilizer will have a significant effect on increasing the production of curly red chilies by 0.005%, assuming other inputs remain constant. On average, KCl use reaches 165.82 kg per hectare, compared with the recommended dosage of 200 kg per hectare. As a result, increasing KCl application toward the recommended level still offers potential for improving production performance.

The manure variable has a coefficient value of -0.045 at a 95% partial confidence level. This means that the addition of 1% manure variable has a significant effect on the decrease in curly red chili production by 0.045%, assuming other inputs remain constant.

The liquid insecticide variable shows a negative coefficient value of (-0.007) at a 99% partial confidence level. This means that the addition of a 1% liquid insecticide variable has a significant effect on reducing the production of curly red chilies by 0.007%.

The labor input exhibits a positive and statistically significant coefficient of 0.171 at the 99% partial confidence level. This indicates that a 1% increase in labor use is associated with a substantial increase in curly red chili output by 0.171%, holding other inputs constant. In Kapanewon Galur, the labor variable has a positive and statistically significant coefficient indicating that increased labor use contributes positively to output. This coordination enables synchronized planting in the subsequent season and ensures that land sterilization processes are not omitted. Consequently, harvesting operations particularly during peak periods, which typically occur between the third and fifth harvests are highly labor-intensive.

Table 1. Estimation results of the Cobb-Douglas type production function using the stochastic frontier approach

Variables	Parameter	Coefficient	t-count
constant	b ₀	1.508***	5.986
Land area	b ₁	0.800***	19.835
Seeds	b ₂	0.023	0.527
NPK fertilizer	b ₃	0.004	0.132
KCl fertilizer	b ₄	0.005***	2.665
Pupuk ZA	b ₅	-0.006	-0.628
Phonska Fertilizer	b ₆	-0.000	-0.191
KNO ₃ fertilizers red	b ₇	-0.001	-0.550
Manure	b ₈	-0.045**	-2.054
Liquid herbicide	b ₉	-0.002	-0.884
Liquid insecticide	b ₁₀	-0.007***	-2.951
Liquid fungicide	b ₁₁	-0.002	-1.066
Solid insecticide	b ₁₂	-0.001	-0.590
Solid fungicide	b ₁₃	0.002	0.533
Labor	b ₁₄	0.171***	4.470
Sigma-square (σ^2)		0.026**	2.225
Gamma (γ)		0.870***	5.558

Note: ***: Significant effect at the α level of 1% (t-table = 2.632), **: Significant effect at the α level of 5% (t-table = 1.987), *: Significant effect at the α level of 10% (t-table = 1.662). Source: Created by author

The remaining production factors including seeds, NPK fertilizer, ZA fertilizer, Phonska fertilizer, KNO₃ fertilizer, liquid herbicide, liquid fungicide, solid insecticide, and solid fungicide were found to be statistically non-significant. This suggests that variations in these inputs did not contribute meaningfully to differences in chili output among farmers. In coastal sandy soils, this pattern is likely associated with input misallocation, where fertilizers and agrochemicals are often applied either in excess or below optimal levels, reducing their marginal productivity.

Technical efficiency analysis of curly red chili farming

Curly red chili pepper farming in Kulon Progo can be considered efficient if it achieves maximum production using a specific set of production factors. Using Frontier 4.1, the technical efficiency level of each sample in this study can be analyzed, with results ranging from 0 to 1.

Table 2 shows that curly red chili farming in the coastal area was technically efficient under both irrigation systems, as the average technical efficiency values of both groups were above 0.700. This indicates that farmers were generally able to achieve relatively high output through the combination of various production factors such as land area, seeds, NPK fertilizer, KCl fertilizer, ZA fertilizer, phonska fertilizer, KNO₃ fertilizer, manure, liquid herbicide, liquid insecticide, liquid fungicide, solid insecticide, solid fungicide, and labor.

However, farmers using sprinkler irrigation achieved a higher average technical efficiency (0.902) than those using shower irrigation (0.795), indicating that sprinkler irrigation was more effective in bringing farmers closer to the production frontier. Based on direct interviews, farmers explained that sprinkler irrigation distributed water more evenly across the planting area, which was particularly important under sandy coastal soil conditions where water infiltrates rapidly. Farmers also reported that the sprinkler system was more practical and easier to manage during the dry season because water application could be carried out

more regularly and efficiently. In contrast, shower irrigation relied more on manual operation, so water distribution was often less uniform and more dependent on labor performance in the field. As a result, sprinkler irrigation was perceived by farmers to better maintain soil moisture, support more uniform plant growth, and improve the effectiveness of other production inputs, which ultimately contributed to its higher technical efficiency compared to the shower system.

Analysis of technical inefficiency factors in curly red chili farming

The variables suspected of influencing the technical inefficiency of curly red chili farming were analyzed simultaneously using the Frontier 4.1 application as variable Z. The estimated technical inefficiency factors are presented in Table 3.

The irrigation type variable (D4) has a positive coefficient of 0.021 and is statistically significant at the 5% level. This indicates that farmers using shower irrigation (D4 = 1) tend to have higher technical inefficiency compared to those using sprinkler irrigation (D4 = 0), *ceteris paribus*. This result suggests that the choice of irrigation system plays an important role in determining the efficiency of curly red chili farming in coastal areas. It is known that the irrigation type variable has a significant effect on the technical inefficiency of farming. The types of agricultural land irrigation for curly red chili farming in the coastal areas are shower irrigation and sprinkler irrigation. The dummy variable of irrigation type has a calculated t-value (2.142) greater than the t-table value (1.987) at the α level of 5% with a positive coefficient value (0.021). This means that the dummy variable of irrigation type has a significant effect on the technical inefficiency of curly red chili farming. The analysis shows a positive coefficient, which means that farmers with shower irrigation technically inefficient than sprinkler irrigation.

Table 2. Distribution of technical efficiency levels of curly red chili farmers in the coastal lands

Technical efficiency level	Number of farmers		
	Sprinkle	Shower	Total
≤0.700	2	13	15
0.701-0.800	0	29	29
0.801-0.900	6	33	39
0.901-1.000	20	7	27
Total	28	82	110
Minimum Technical Efficiency Level	0.562	0.581	0.562
Maximum Technical Efficiency Level	0.966	0.980	0.980
Average Technical Efficiency Level	0.902	0.795	0.822

Source: Created by author

Table 3. Technical inefficiency factors of curly red chili farming in the coastal land

Variables	Parameter	Coefficient	T count
constant	d ₀	0,128	0.325
Age	d ₁	0,020	0.194
Education	d ₂	-0.008	-0.544
Red Chili Farming	d ₃	-0.002	-0.056
Experience			
Types of Irrigation	d ₄	0.021**	2.142
Types of Seed Varieties	d ₅	-0.006	-1.453

Note: ***: Significant effect at the α level of 1% (t-table = 2.632), **: Significant effect at the α level of 5% (t-table = 1.987), *: Significant effect at the α level of 10% (t-table = 1.662). Source: Created by author

Farmers using sprinkler irrigation are more labor-efficient in watering activities than shower irrigation. With the same 1 hectare of land being worked by one person, sprinkler irrigation farmers only need 2 hours, while shower irrigation farmers need three times as long, namely 6 hours, to complete the watering activity. The inefficiency model shows that irrigation type (D4) has a positive and significant coefficient (0.021), indicating that shower irrigation is associated with higher technical inefficiency compared to sprinkler irrigation. This suggests that sprinkler irrigation systems are more effective in improving production efficiency under coastal conditions. In addition, watering using sprinklers is distributed more evenly than showers because the sprinkler will rotate to release water discharge at the same speed at a predetermined time. This causes plants under sprinkler irrigation to have more even fertility to produce more curly red chilies.

The variables of age, education, experience in red chili farming, and seed variety did not have a significant effect on technical inefficiency. The farmer's age variable was not significant because farmers still use cultivation methods passed down through generations by their families. The analysis results showed a positive coefficient value, indicating that as farmers age, the level of technical inefficiency tends to increase. Older farmers have a decreased physical work capacity and find it difficult to accept innovation, so they do not utilize technology to develop their farming businesses. The variable of education level was not significant on inefficiency because formal education in schools did not focus on how to manage farming, especially curly red chili commodities.

The red chili farming experience variable does not significantly influence inefficiency because not all farmers with more experience are unwilling to accept emerging agricultural innovations. Some farmers are aware that one way to improve their farming practices, which have been using traditional methods for years, is by adapting to developments in cultivation and technology.

The dummy variable for seed variety type does not significantly influence inefficiency because both jitu and laba varieties are good quality. However, the negative coefficient value (-0.006) indicates that farmers using jitu seed varieties tend to be more efficient because jitu seed varieties produce chilies that have heavier fruit weight than laba seed varieties. In one sack of the same size, jitu variety chilies can reach 30 kg while laba varieties only reach 25 kg. Despite this, some farmers still use laba seed varieties because the price of laba seeds is lower than jitu seeds. In addition, the reason farmers choose laba seeds is that they have been used for generations.

The technical efficiency level of 0.822 obtained in this study is comparable to efficiency estimates reported in other chili-producing regions in Indonesia and developing countries. Studies in Bogor and Tuban, Indonesia, as well as in Ethiopia and Ghana, reported technical efficiency levels ranging between 0.70 and 0.85, indicating that coastal chili farmers in Kulon Progo perform within a similar efficiency range despite operating under more challenging sandy and saline soil conditions. This suggests that irrigation technology plays a crucial role in

compensating for the inherent limitations of coastal environments.

From a practical perspective, the results imply that farmers can improve productivity by optimizing land use, labor allocation, and fertilizer management, particularly KCl application. The negative impact of excessive manure and liquid insecticide use indicates the need for better input management through farmer training and extension services. In addition, the higher efficiency of sprinkler irrigation suggests that promoting this irrigation system could help reduce labor costs and improve water distribution, thereby increasing farm efficiency and profitability in coastal areas.

Discussion

In the context of coastal land in Kulon Progo, expanding the cultivation area presents unique challenges due to the high porosity of sandy soils. Therefore, the expansion of land must be accompanied by the implementation of efficient irrigation technologies, such as shower or sprinkler systems, to ensure uniform water distribution across the larger area (Wu et al. 2019). The positive and significant coefficient of land area (0.800) indicates that expanding cultivated area increases curly red chili production, as farmers are able to plant more chili stands, thereby increasing overall output a finding consistent with evidence from Bogor District, Indonesia (Sinatria et al. 2022). The positive impact of labor (0.171) is also critical because harvesting operations particularly during peak periods are highly labor-intensive. These findings are consistent with previous studies conducted in Pidie Jaya District, Indonesia, by Yusmaini et al. (2021) and research in Ethiopia by Abate et al. (2019) which report that more optimal labor allocation contributes to higher output levels.

The effectiveness of chemical and organic inputs is heavily influenced by the unique characteristics of coastal sandy soils. The positive coefficient of KCl fertilizer (0.005) indicates that increasing its application contributes to higher production. This finding differs from evidence reported in Tanah Datar District, where KCl fertilizer was found to have no significant effect on curly red chili production because application rates exceeded recommended levels (Chaniago et al. 2025). In coastal sandy soils, KCl helps support physiological growth under high water-percolation conditions, especially when dissolved optimally by sprinkler irrigation (Rahmadanti et al. 2021; Qu et al. 2024). Conversely, the negative and significant coefficient of manure (-0.045) indicates that a 1% increase in manure use reduces production by 4.5% (Rathnayake et al. 2023). This may be attributed to the application of wet or immature manure, which differs from research in Pagar Alam City where dry manure at recommended levels increased output (Maryanto et al. 2018; Salsabilah et al. 2023). In sandy soil, non-optimal applications can accelerate nutrient leaching or cause microbial imbalances (Sun et al. 2022; Heydarzadeh et al. 2023; Qu et al. 2024).

The negative coefficient of liquid insecticide (-0.007) suggests that increased application is associated with lower

production. This may occur because farmers often apply liquid insecticides at doses exceeding recommended levels to prevent pest resistance or to compensate for “wash-off” effects caused by overhead irrigation, which ultimately reduces plant productivity (Abate et al. 2019; Elhamalawy et al. 2024). This finding is not consistent with evidence from Rengel District, where liquid insecticides significantly affected productivity (Mukti et al. 2022). This outcome is consistent with the Law of Diminishing Returns, where excessive fertilizers and pesticides in fragile coastal agro-ecosystems degrade soil quality, disrupt beneficial organisms, and reduce nutrient efficiency (Sonia et al. 2020; Hossain and Li 2024; Xiang and Lv 2025). The non-significance of other inputs like seeds, NPK, and ZA highlights the importance of precision input management rather than intensification in coastal chili farming.

The average technical efficiency level of both irrigation type is above 0.700 indicates that farmers are operating relatively efficiently, performing within a similar range as other regions like Bogor (Indonesia), Tuban (Indonesia), Ethiopia, and Ghana (0.70-0.85) (Asravor et al. 2016; Yohannis et al. 2020; Sinatria et al. 2022; Mukti et al. 2022). The significant effect of irrigation type confirms that sprinkler irrigation is more efficient than shower irrigation due to more uniform water distribution and reduced labor requirements. For instance, watering 1 hectare with sprinklers takes only 2 hours, compared to 6 hours with shower irrigation. Regarding socio-economic factors, the non-significance of experience is inconsistent with research in Karangnangka Village, Sumenep, Indonesia that found experience significantly reduces technical inefficiency (Salsabilah et al. 2023). In Kapanewon Galur, older farmers may find it difficult to accept innovations like sprinkler technology. Similarly, the education variable was insignificant, suggesting that formal schooling does not necessarily translate to technical competencies like water scheduling, where specific practical training is more critical (Huang and Hartemink 2020; Workneh and Kumar 2023; Ramdan et al. 2025; Rahayu and Pracia 2025).

In conclusion, this study determines that land area, KCl fertilizer, and labor are the primary factors positively influencing production, while excessive manure and liquid insecticide negatively impact output. Curly red chili farming in Kulon Progo achieved a relatively high average technical efficiency of 0.822. Moreover, sprinkler irrigation was more efficient than shower irrigation, with average technical efficiency scores of 0.902 and 0.795, respectively, indicating that sprinkler irrigation systems were significantly more effective than shower systems in reducing technical inefficiency. These results imply that farmers can improve productivity by optimizing land use and KCl management while shifting toward sprinkler irrigation to reduce labor costs and improve water distribution. However, this study has several limitations, including the use of cross-sectional data which limits the ability to capture seasonal dynamics in efficiency. Additionally, some relevant variables such as specific irrigation scheduling, soil salinity variation, and extension

access were not included due to data constraints, suggesting that future research should consider panel data approaches and more detailed irrigation management indicators to better understand efficiency dynamics in coastal agricultural systems.

REFERENCES

- Abate TM, Dessie AB, Mekie TM. 2019. Technical efficiency of smallholder farmers in red pepper production in North Gondar Zone Amhara Regional State, Ethiopia. *J Econ Struct* 8 (1): 18. <https://doi.org/10.1186/s40008-019-0150-6>.
- Angélica A MP, Aleman CC, Eslamian S. 2023. Economic viability of irrigation techniques. In: Eslamian S, Eslamian F (eds.). *Handbook of Irrigation Hydrology and Management: Irrigation Fundamentals*. CRC Press, Boca Raton. <https://doi.org/10.1201/9780429290114-12>.
- Asravor J, Onumah EE, Osei-Asare YB. 2016. Efficiency of chili pepper production in the volta region of Ghana. *J Agric Ext Rural Dev* 8 (6): 99-110. <https://doi.org/10.5897/JAERD2016.0765>.
- Badan Pusat Statistik (BPS) Kabupaten Kulon Progo. 2025. Kecamatan Galur dalam Angka 2025. BPS Kabupaten Kulon Progo, Kulon Progo. [Indonesian]
- Battese GE, Coelli TJ. 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empir Econ* 20 (2): 325-332. <https://doi.org/10.1007/BF01205442>.
- Berger AN, Humphrey DB. 1997. Efficiency of financial institutions: International survey and directions for future research. *Eur J Oper Res* 98 (2): 175-212. [https://doi.org/10.1016/S0377-2217\(96\)00342-6](https://doi.org/10.1016/S0377-2217(96)00342-6).
- Cao X, Sun B, Chen H, Zhou J, Song X, Liu X, Deng X, Li X, Zhao Y, Zhang J, Li J. 2021. Approaches and research progresses of marginal land productivity expansion and ecological benefit improvement in China. *Bull Chin Acad Sci* 36 (3): 336-348. <https://doi.org/10.16418/j.issn.1000-3045.20201228002>.
- Chaniago P, Syahni R, Hafizah D. 2025. Analisis efisiensi teknis usaha tani cabai merah keriting di Kabupaten Tanah Datar. *Jurnal Pertanian Agros* 27 (1): 9-18. <https://doi.org/10.37159/jpa.v27i1.20>. [Indonesian]
- Elhamalawy O, Bakr A, Eissa F. 2024. Impact of pesticides on non-target invertebrates in agricultural ecosystems. *Pestic Biochem Physiol* 202: 105974. <https://doi.org/10.1016/j.pestbp.2024.105974>.
- Färe R, Lovell CK. 1978. Measuring the technical efficiency of production. *J Econ Theor* 19: 150-162. [https://doi.org/10.1016/0022-0531\(78\)90060-1](https://doi.org/10.1016/0022-0531(78)90060-1).
- Ghirardelli A, Traffellini E, Park E, D'Agostino V, Masin R, Tarolli P. 2025. Global impact of seawater intrusion on coastal agriculture. *Environ Res Lett* 20 (1): 013005. <https://doi.org/10.1088/1748-9326/ad9bcd>.
- Heydarzadeh S, Arena C, Vitale E, Rahimi A, Mirzapour M, Nasar J, Kisaka O, Sow S, Ranjan S, Gitari H. 2023. Impact of different fertilizer sources under supplemental irrigation and rainfed conditions on eco-physiological responses and yield characteristics of dragon's head (*Lallemantia iberica*). *Plants* 12 (8): 1693. <https://doi.org/10.3390/plants12081693>.
- Hossain ML, Li J. 2024. Salinity challenges and adaptive strategies in salinization-affected coastal Bangladesh: Implications for agricultural sustainability and water resource management. *Environ Res Lett* 19 (11): 114048. <https://doi.org/10.1088/1748-9326/ad7edb>.
- Huang J, Hartemink AE. 2020. Soil and environmental issues in sandy soils. *Earth Sci Rev* 208: 103295. <https://doi.org/10.1016/j.earscirev.2020.103295>.
- Islam F, Alam GMM, Begum R, Sarker MNI, Bhandari H. 2021. Vulnerability, food security and adaptation to climate change of coastal rice farmers in Bangladesh. In: Alam GMM, Erdiaw-Kwasie MO, Nagy GJ, Leal Filho W (eds.). *Climate Vulnerability and Resilience in the Global South: Human Adaptations for Sustainable Futures*. Springer, Cham. https://doi.org/10.1007/978-3-030-77259-8_9.
- Maryanto MA, Sukiyono K, Sigit Priyono B. 2018. Analisis efisiensi teknis dan faktor penentu pada usahatani kentang (*Solanum tuberosum* L.) di Kota Pagar Alam, Provinsi Sumatera Selatan.

- AGRARIS: J Agribus Rural Dev Res 4 (1): 1-8. <https://doi.org/10.18196/agr.4154>. [Indonesian]
- Mukti MW, Fikry MA, Tama FN, Qowim MM, Fanany AI. 2022. Efisiensi teknis pada petani cabai merah besar mitra indofood di Kecamatan Rengel Kabupaten Tuban. *Jurnal Agriuma* 4 (2): 65-70. <https://doi.org/10.31289/agri.v4i2.7530>. [Indonesian]
- Narayanamoorthy A, Jothi P, Suresh R, Sujith KS. 2024. Can drip method of irrigation transform yield and income of horticultural crops? Evidence of five crops from Tamil Nadu. *Indian J Agric Econ* 79 (3): 455-468. <https://doi.org/10.63040/25827510.2024.03.010>.
- Pittalis D, Carletti A, Ghiglieri G, Celico F. 2016. The influence of hydrogeological properties, seawater intrusion and refreshing on the quality of groundwater used for irrigation in an agricultural coastal plain in North Sardinia, Italy. *Environ Earth Sci* 75 (11): 963. <https://doi.org/10.1007/s12665-016-5770-7>.
- Qu Z, Chen Q, Yin S, Feng H, Liu Y, Li C. 2024. Effects of drip irrigation coupled with controlled release potassium fertilizer on maize growth and soil properties. *Agric Water Manag* 301: 108948. <https://doi.org/10.1016/j.agwat.2024.108948>.
- Rahayu L, Pracia DA. 2025. Technical efficiency of inpari IR nutri zinc rice farming in Bantul Regency, Yogyakarta, Indonesia. *E3S Web Conf* 665: 01014. <https://doi.org/10.1051/e3sconf/202566501014>.
- Rahmadanti IS, Zakaria WA, Marlina L. 2021. Analisis pendapatan usahatani dan faktor-faktor yang mempengaruhi produksi cabai merah di Desa Trimulyo Kecamatan Tegineneng Kabupaten Pesawaran. *Jurnal Ilmu-Ilmu Agribisnis* 8 (2): 183. <https://doi.org/10.23960/jiia.v9i2.5074>. [Indonesian]
- Ramdan AW, Aisyah A, Sugeru H, Asnur P, Fahnum BU. 2025. Effects of biological fertilizer and NPK on red chili growth in automated drip irrigation systems. *Jurnal Biologi Tropis* 25 (1): 787-794. <https://doi.org/10.29303/jbt.v25i1.8566>.
- Rao KVR, Gangwar S, Bajpai A, Keshri R, Chourasia L, Soni K. 2017. Performance of pea under different irrigation systems. *Legume Res Intl J* 40 (3): 559-561. <https://doi.org/10.18805/lr.v0iOF.4482>.
- Rathnayake D, Schmidt H, Leifeld J, Mayer J, Epper CA, Bucheli TD, Hagemann N. 2023. Biochar from animal manure: A critical assessment on technical feasibility, economic viability, and ecological impact. *GCB Bioenergy* 15 (9): 1078-1104. <https://doi.org/10.1111/gcbb.13082>.
- Rodrigues GC, Paredes P, Gonçalves JM, Alves I, Pereira LS. 2013. Comparing sprinkler and drip irrigation systems for full and deficit irrigated maize using multicriteria analysis and simulation modelling: Ranking for water saving vs. farm economic returns. *Agric Water Manag* 126: 85-96. <https://doi.org/10.1016/j.agwat.2013.05.005>.
- Salsabilah S, Febriyana ND, Ainiyah Z, Kholifah AN, Agustina NH. 2023. Analisis efisiensi terhadap usahatani cabai rawit (Studi kasus Desa Karangnangka Kec. Rubaru, Kab. Sumenep). *Jurnal Ekonomi Pertanian dan Agribisnis* 7 (2): 809-819. <https://doi.org/10.21776/ub.jepa.2023.007.02.32>. [Indonesian]
- Sinatria T, Fariyanti A, Hidayat NK. 2022. Analisis efisiensi teknis usahatani cabai merah keriting dan preferensi risiko petani di Kabupaten Bogor. *Syntax Literate: Jurnal Ilmiah Indonesia* 7 (3): 3285-3296. <https://doi.org/10.36418/syntax-literate.v7i3.6614>. [Indonesian]
- Singh HP, Singh B. 2020. Micro-irrigation in India: An option for improving water productivity and profitability. *Acta Hort* 1279: 279-285. <https://doi.org/10.17660/ActaHortic.2020.1279.40>.
- Sonia T, Karyani T, Susanto A. 2020. Analisis efisiensi alokatif usaha tani cabai merah besar di Desa Sukalaksana Kecamatan Banyuresmi Kabupaten Garut. *Mimbar Agribisnis: Jurnal Pemikiran Masyarakat Ilmiah Berwawasan Agribisnis* 6 (1): 19-32. <https://doi.org/10.25157/ma.v6i1.2613>. [Indonesian]
- Sun Z, Lin M, Du C, Hao Y, Zhang Y, Wang Z. 2022. The use of manure shifts the response of α -diversity and network while not β -diversity of soil microbes to altered irrigation regimes. *Appl Soil Ecol* 174: 104423. <https://doi.org/10.1016/j.apsoil.2022.104423>.
- Suprayogi, Dewi PS, Oktaviani, E, Aisyah AW. 2022. Marker validation for salt tolerance in Indica rice. *Biodiversitas* 23: 4517-4523. <https://doi.org/10.13057/biodiv/d230918>.
- Workneh WM, Kumar R. 2023. The technical efficiency of large-scale agricultural investment in Northwest Ethiopia: A stochastic frontier approach. *Heliyon* 9 (9): e19572. <https://doi.org/10.1016/j.heliyon.2023.e19572>.
- Wu D, Xu X, Chen Y, Shao H, Sokolowski E, Mi G. 2019. Effect of different drip fertigation methods on maize yield, nutrient and water productivity in two-soils in Northeast China. *Agric Water Manag* 213: 200-211. <https://doi.org/10.1016/j.agwat.2018.10.018>.
- Xiang Y, Lv Y. 2025. Research on the connection between sustainable rural economic growth and the usage of chemicals in rural areas. *Chem Prod Process Model*. <https://doi.org/10.1515/cppm-2024-0104>.
- Yohannis T, Tenaye A, Ganewo Z. 2020. Technical efficiency of agricultural production in Ethiopia. *J Nat Sci Res* 10 (5): 46-54. <https://doi.org/10.7176/jnsr/10-5-05>.
- Yusmaini, Usman M, Safrida, Kasimin S. 2021. Efficiency analysis of red chili farming in Pidie Jaya Aceh. *IOP Conf Ser Earth Environ Sci* 644 (1): 012066. <https://doi.org/10.1088/1755-1315/644/1/012066>.