

Improving Shallot Farm Business Performance Through Resource Management Efficiency: A Stochastic Frontier Analysis

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Abstract

Demand for shallots has steadily increased over time, while production remains seasonal and suboptimal, limiting consistent fulfilment of domestic demand. Expanding output through increased input use or new technologies is costly. Improving efficiency is a more feasible and economically rational strategy. Farmers' capacity to optimally combine production factors critically influences farm performance and potential output and narrowing the supply gap. So, the appropriate allocation of inputs and the attainment of technical efficiency (TE) are essential for increasing agricultural output. This study examines seasonal differences in technical efficiency and identifies the determinants of inefficiency in shallot farming in Garut Regency. Using purposive sampling, 100 shallot farmers were selected. TE was estimated using Stochastic Frontier Analysis with a Cobb-Douglas production function specification. The findings show significant differences in productivity and TE between the dry and rainy seasons, with a mean TE of 0.931 in the rainy season and 0.844 in the dry season. These results indicate potential output gains of 7.41% and 18.48%, respectively, through full attainment of technical efficiency. The determinants of technical inefficiency include planting density, mechanization, farming experience, membership in farmer groups, and land tenure status.

Keywords: cobb-douglas; comparative; production; technical efficiency

INTRODUCTION

Shallots (*Allium ascalonicum* L.) are a high-value agricultural commodity and one of Indonesia's strategic food commodities that significantly influence inflation.

Demand is expected to continue increasing with population growth, while consumption in Indonesia has risen at an average annual rate of 3.48% (Sitohang & Nainggolan, 2024). In contrast, shallot production remains fluctuating and suboptimal, with

average productivity reaching only 10.32 tons/ha. This is far below the ASEAN average of 16.48 tons/ha and the levels in countries such as New Zealand and China, which exceed 30 tons/ha. This gap between rising demand and unstable production challenges the adequate and reliable supply of shallots.

Inefficient use of production factors prevents farms from reaching their potential output. Because shallot production remains below its potential, there is considerable scope to increase output through productivity improvements (Nurjati et al., 2018). Improving productivity through expanding input and adopting new technologies can be difficult in the short term because both often require substantial financial investment. Improving efficiency is more feasible and economically rational alternative because farmers may increase production and profitability despite resource constraints.

The development of shallot farming, particularly in major production areas, requires adequate support so farms can achieve their production potential. Indonesia's main shallot-producing areas are concentrated on Java Island. Since 2015, Garut Regency in West Java Province has been developed as one of the country's shallot production centers. Yet Garut Regency has consistently recorded the lowest productivity among major shallot-producing regions in West Java. This low productivity also indicates substantial scope to improve

production and move closer to the attainable production frontier.

Farmers' ability to combine production inputs appropriately has a direct influence on farm output. Seed use and cultivated land area are among the most significant and dominant determinants of shallot production (Junaidi et al., 2020; Mahananto et al., 2021; Marina et al., 2023; Puryantoro & Wardiyanto, 2022). These findings suggest that shallot production may still depend primarily on the scale of cultivated land rather than on differences in the quality and efficiency of production management.

The effectiveness with which farmers manage production factors can be reflected in their level of efficiency. Technical efficiency refers to the maximum attainable output from a given set of inputs under a given technology (Farrell, 1957). Accordingly, the achievement of technical efficiency constitutes an important indicator of production potential and the appropriateness of input utilization at the farm level (Karo-karo et al., 2021).

An assessment of technical efficiency is therefore an important step toward increasing shallot production and promoting more sustainable farming systems. By quantifying the level of farm efficiency, it is possible to determine the extent to which production can be increased through improved resource allocation and management. Studies of farm efficiency have been conducted across a wide range of agricultural commodities. Karo-karo et al. (2021), for example, examined efficiency in cabbage farming; Yofa et al. (2021)

investigated the efficiency of maize farming; Danasari et al. (2023) analyzed technical efficiency in garlic production; while Astuti et al. (2020) and Wiharjo et al. (2021) assessed efficiency in shallot farming. Previous estimates of technical efficiency in shallot farming have generally indicated relatively high, but still suboptimal, levels, with mean efficiency scores of 0.786 (Nainggolan et al., 2023), 0.897 (Astuti et al., 2020), and 0.864 (Utari et al., 2022). These findings indicate that the management of production factors remains suboptimal. The existing combination of inputs has not enabled farmers to maximize output, suggesting that considerable technical inefficiency persists and that further gains in production remain possible.

This study specifically addresses the gap in comparative evidence on dry-season and rainy-season shallot farming in Garut Regency, which has not been examined in previous studies. Comparing the dry and rainy seasons is important. It supports season-specific extension timing and more targeted seasonal input-support policies by identifying when production constraints are more strongly linked to environmental conditions or farm management. It also evaluates farmers' tendency to apply fertilizers excessively to assess its implications for environmental sustainability and farm performance. Accordingly, this study aims to analyze the technical efficiency of shallot farming in Garut Regency and identify the determinants of technical inefficiency.

METHOD

Research Data

The study was conducted in Garut Regency, chosen for its relatively low shallot productivity despite its development as one of the major shallot-producing areas in West Java. Sampling was conducted in Bayongbong District because it has the largest harvested area, covering 1,791 ha (49.05%), and the highest production, amounting to 17,718 tons (49.22%). These considerations were expected to ensure that the data collected adequately represented shallot farming conditions in Garut Regency.

Primary cross-sectional data were collected through direct interviews with 100 shallot farmers using structured questionnaires. The sample comprised 70 shallot farms during the rainy season and 30 farms during the dry season, reflecting the smaller number of farmers cultivating shallots during the dry season. The rainy- and dry-season observations came from two different groups of farms; we did not track the same farms across seasons. Therefore, the seasonal comparison is based on cross-sectional samples rather than repeated observations of the same farms. Respondents were selected using purposive sampling. The inclusion criterion was a monoculture shallot farm that had remained in production during the preceding year.

Technical Efficiency of Shallot Farming Analysis

A production function represents the technical relationship through which inputs are transformed into

output (Debertin, 2012). Coelli et al. (2005) explained that the production function corresponds to the production frontier. A frontier production function indicates the position of actual production relative to the production frontier. Its principal advantages are its ability to analyze technical efficiency (TE) and inefficiency in the production process. It also examine internal and external determinants of TE and identify factors affecting inefficiency simultaneously (Machmuddin, 2017; Rifaini et al., 2022).

This study employed Stochastic Frontier Analysis (SFA) based on a Cobb-Douglas production function to estimate TE. The production function for shallot farming is as follows:

$$Y_i = \alpha X_1^{\beta_1} X_2^{\beta_2} X_3^{\beta_3} X_4^{\beta_4} X_5^{\beta_5} X_6^{\beta_6} X_7^{\beta_7} e^{\varepsilon} \quad (1)$$

The stochastic production function consists of two error (ε) components, v_i and u_i . v_i represents external factors such as climatic conditions, pest and disease attacks, and input variables not explicitly specified in the model. Meanwhile, u_i represents internal factors associated with technical inefficiency. All variables were standardized by cultivated land area (ha); consequently, land area was not included explicitly in the production function. The production function was subsequently transformed into a multiple linear regression form using the natural logarithmic transformation (ln).

$$\ln Y_i = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + \beta_6 \ln X_6 + \beta_7 \ln X_7 + v_i - u_i \quad (3)$$

Variable definitions:

- Y_i = shallot production (kg/ha)
- X_1 = seed quantity (kg/ha)
- X_2 = organic fertilizer (kg/ha)
- X_3 = inorganic fertilizer (kg/ha)
- X_4 = pesticide use (liter/ha)
- X_5 = male labor (HOK/ha)
- X_6 = female labor (HOK/ha)
- X_7 = planting season (1=dry season, 0=rainy season)
- β_0 = intercept
- β_i = estimated coefficient
- v_i = random error component
- u_i = non-negative error component associated with technical inefficiency

The production function was estimated using Frontier 4.1 through the Maximum Likelihood Estimation (MLE) method. The estimated model was subsequently used to derive technical efficiency for each farm. The calculation of TE followed Coelli et al. (2005):

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{\exp(x_i \beta - u_i)}{\exp(x_i \beta)} = \exp(-u_i) \quad (4)$$

Where:

- TE = technical efficiency
- Y_i = observed output
- Y_i^* = frontier output

A farm was categorized as technically efficient when its TE score exceeded 0.70 (Coelli et al., 2005).

Determinants of Technical Inefficiency Analysis

The technical inefficiency effects model follows Battese & Coelli (1992). Technical inefficiency is represented by the u_i component of the production function. The technical inefficiency effects model was specified using the following determinants:

$$u_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \delta_7 Z_7 + \delta_8 Z_8 + W_i \quad (5)$$

Where:

u_i = technical inefficiency effect

Z_1 = nitrogen residue (kg/ha)

Z_2 = plant density

Z_3 = mechanization (1 = mechanical sprayer; 0 = manual sprayer)

Z_4 = farmer age (years)

Z_5 = farming experience (years)

Z_6 = farmer-group membership (1= member; 0=non-member)

Z_7 = participation in agricultural extension (1= yes; 0=no)

Z_8 = land tenure status (1= owner; 0=rented)

A likelihood-ratio (LR) test was subsequently conducted to determine whether technical inefficiency effects were present in the model. The LR statistics were calculated as:

$$LR = -2 \left[\ln \left(\frac{L_r}{L_u} \right) \right] = -2 [\ln(L_r) - \ln(L_u)] \quad (6)$$

Where:

LR = likelihood ratio statistic

L_r = Likelihood under OLS

L_u = Likelihood under MLE

The decision criterion:

$LR > \chi^2_{\text{restriction}}$ technical inefficiency effects are present in the model.

$LR < \chi^2_{\text{restriction}}$ technical inefficiency effects are not present in the model.

The variance components are expressed in parameter form as:

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 \quad (7)$$

$$\gamma = \frac{\sigma_u^2}{\sigma^2} \quad (8)$$

The value of γ indicating the contribution of technical inefficiency to the total residual variance. A smaller γ (approaching 0) indicates that random noise is more dominant in explaining variations in output. A γ value approaching 1 indicates that technical inefficiency is the dominant source of variation.

RESULT AND DISCUSSION

Technical Efficiency of Shallot Farming

The estimated production-function using the Maximum Likelihood Estimation (MLE) method is presented in Table 1. In the Cobb-Douglas production function, the estimated regression coefficients (β_i) represent production elasticities.

Table 1. Production function of shallot farming in Garut Regency

Variable	Rainy season		Dry Season		Pooled model	
	coef.	t-ratio	coef.	t-ratio	coef.	t-ratio
Intercept	1.673	**3.704	2.578	**12.521	1.969	**5.258
X_1 Seed	0.184	1.576	0.073	1.296	0.197	**2.424
X_2 Organic fertilizer	0.463	**3.938	0.489	**6.832	0.426	**4.795
X_3 Inorganic fertilizer	0.098	1.125	0.142	**4.783	0.102	*1.698
X_4 Pesticides	0.045	0.901	0.084	**4.563	0.065	1.566
X_5 Male labor	0.169	**2.094	0.044	0.997	0.129	**2.498
X_6 Female labor	0.086	*1.832	0.088	**4.897	0.089	**2.685
X_7 Planting season					0.248	**4.225

Note: ** significant at $\alpha = 5\%$ (0.05), * $\alpha = 10\%$ (0.10)

Seed use had a significant positive effect on shallot output in the pooled model, with an elasticity of 0.197. This indicates that a 10% increase in seed use would increase shallot output by 1.97%, *ceteris paribus*. This finding is consistent with Nainggolan et al. (2023), who reported a significant seed coefficient of 0.474. High-quality seeds are an important determinant of shallot production. Farmers in Garut Regency used the Tuk Tuk variety (93%), Rubaru Sumenep (4%), and Jalaksana (3%). Farmers reported that Sumenep seed were more resistant to pest and disease attacks; however, their relatively high price limited farmers' access.

Seed use remained within the recommended range of 1,200 – 1,800 kg/ha (BI, 2013). As Atman et al. (2022) note, seed use can be optimized by establishing appropriate planting distance. Therefore, regulate planting spacing and adjust it to land characteristics and the planting season. Use high-quality seed with appropriate planting density to improve plant development and ultimately increase yield.

Organic fertilizer had a significant positive effect in both seasons, with elasticities of 0.443 in the rainy season and 0.489 in the dry season. These coefficients imply that a 10% increase in organic fertilizer use would increase shallot output by 4.43% and 4.89%, respectively. Organic fertilizer exhibited the largest production elasticity, indicating its relatively substantial contribution to shallot output. This finding suggests that better organic fertilizer management may offer considerable

potential. This interpretation is supported by Hantari et al. (2025). Organic fertilizers offer several advantages, including a broad nutrient composition, improvements in soil structure, greater soil water-holding capacity, and enhanced nutrient retention (Ibrahim et al., 2021; Mendrofa & Gulo, 2024). The recommended application rate for shallot production is 6,000 – 10,000 kg/ha (BI, 2013). Farmers applied an average of 6,730 – 7,015 kg/ha. This suggests that organic fertilizer application could still be increased within recommended limits.

Inorganic fertilizers were not analyzed separately by fertilizer type, such as NPK, urea, TSP, KCl, and ZA. Instead, the analysis was based on the nutrient content of nitrogen (N), phosphorus (P), and potassium (K) in the respective fertilizers. The results show that inorganic fertilizer had a significant effect only during the dry season. Its use tended to exceed the recommended application rates. Applications of urea, TSP, KCl, and ZA exceeded recommended levels by approximately 30–100%. Although inorganic fertilizers supply essential nutrients for plant growth, excessive application can adversely affect both farm performance and the environment (Yuhendra et al., 2022). The elasticity of inorganic fertilizer was 0.142, indicating that a 10% increase in inorganic fertilizer use would increase output by 1.42%.

Pesticide use had a significant effect on shallot output during the dry season but not during the rainy season. The pesticide elasticity of 0.084 indicates that a 10% increase in

pesticide use would increase output by 0.84%. During the rainy season, spraying frequency was approximately two to three times higher than during the dry season. Farmers sprayed an average of once per week during the dry season but two to three times per week during the rainy season, suggesting that application frequency may have exceeded recommended levels. During the dry season, pesticides were applied mainly, when necessary, particularly when pests or diseases were visibly detected. During the rainy season, however, farmers were more concerned about potential pest and disease outbreaks and consequently sprayed more frequently. Fusarium wilt was identified as a particular challenge during the rainy season and requires timely control measures to reduce pesticide use and minimize the potential adverse effects of pesticide residues on both agricultural output and the environment. Nurhidayati & Wisanggeni (2025) reported that the use of *Streptomyces* S01 in combination with *Bacillus* B16 has potential for controlling Fusarium wilt.

Sinambela (2024), showing that farmers still had inadequate pesticide-management practices in terms of product selection, storage, application, and disposal of pesticide residues. Excessive pesticide use often occurs because application decisions are based primarily on habitual practices and limited farmer knowledge. The large number of pesticide products available also makes it difficult for farmers to identify appropriate products. Therefore, further education and intervention are needed for both

farmers and pesticide suppliers to ensure that accurate and accessible information regarding pesticide selection and application is available.

Male labor had a significant effect only during the rainy season, with an elasticity of 0.163. Thus, a 10% increase in male labor would increase output by 1.63%. Male labor plays an important role in land preparation, pesticide application, and harvesting. During the rainy season, pesticide spraying occurs more frequently than during the dry season, increasing labor requirements.

Female labor had a significant effect in both seasons. The elasticity was 0.091 during the rainy season and 0.088 during the dry season. A 10% increase in female labor would therefore increase output by 0.91% and 0.88%, respectively. This result is consistent with the relatively similar roles of female labor in planting, weed control, and harvesting activities.

The planting-season variable was included only in the pooled production function to assess the effect of seasonal differences. The estimated coefficient was 0.248 and statistically significant, indicating a significant difference in shallot output between the dry and rainy seasons. Shallot farms during the dry season achieved higher output than those during the rainy season. Mutiarasari et al. (2019), reported shallot productivity of 8,329 kg/ha during the dry season, compared with 7,778 kg/ha during the rainy season. These findings demonstrate that planting season is a contextual factor affecting shallot production performance and that output differences are not determined

solely by the quantity of inputs used. The production environment faced by farmers also influences the output that can be achieved from the same resource combination. Differences in seasonal conditions may affect water availability, soil conditions, crop development, and pest and disease pressure.

Technical efficiency (TE) reflects a farm's ability to attain maximum output from a given level of input use and technology (Farrel, 1957). The estimated production frontier represents the maximum attainable production level. Table 2 presents the results of the technical efficiency analysis.

Table 2. Distribution of technical efficiency in shallot farming in Garut Regency

TE	Rainy season		Dry season		Pooled model	
	n	%	n	%	n	%
0.61 - 0.70	1	1.43	6	20.00	5	5.00
0.71 - 0.80	5	7.14	3	10.00	14	14.00
0.81 - 0.90	13	18.57	8	26.67	23	23.00
0.91 - 1.00	51	72.86	13	43.33	58	58.00
Mean	0.931		0.844		0.893	
Min.	0.684		0.613		0.648	
Max.	1.000		0.991		1.000	

Shallot farms in Garut Regency exhibited relatively high TE, although efficiency had not reached its maximum. Mean TE was 0.931 during the rainy season, 0.844 during the dry season, and 0.893 in the pooled model. These results indicate that farms achieved 93.1% of their potential output in the rainy season and 84.4% in the dry season, leaving considerable scope to increase shallot production through improved technical efficiency. The relatively high technical efficiency observed during the rainy season is notable for smallholder farms. One possible explanation is the relatively homogeneous sample, which may imply similar cultivation practices. Consequently, the estimated frontier may be relatively low, resulting in a high ratio of actual to potential output.

High technical efficiency can be interpreted from both positive and negative perspectives. Positively, a high TE score suggests that farmers are

already utilizing available technologies relatively effectively, enabling them to approach their potential production levels. However, it also indicates that further output gains through efficiency improvements alone may be limited. To increase production beyond this level, farmers may therefore need to adopt improved or new technologies. This implication is particularly relevant during the rainy season, when the potential increase in output through full technical efficiency is only 7.41%. Given an average productivity of 9,330 kg/ha, achieving full technical efficiency would increase productivity to approximately 10,021 kg/ha. During the dry season, productivity could increase by 18.48%, from 10,223 kg/ha to 12,112 kg/ha. Thus, the dry season provides greater scope for output improvement through efficiency gains than the rainy season. This finding is consistent with Utari et

al. (2022). The higher technical efficiency observed during the rainy season may be associated with differences in water availability, crop management, and the timing of input application. Nevertheless, causal attribution would require further analysis using panel data or experimental approaches.

Technical efficiency is context-dependent, meaning that the same resource-management practices do not necessarily produce the same efficiency outcomes under different seasonal conditions. Differences in

technical efficiency may arise from socioeconomic factors as well as cultivation practices. The potential for output improvement may therefore be enhanced through better farmer skills and improved cultivation technologies (Nurjati et al., 2018).

Determinants of Technical Inefficiency in Shallot Farming

Reducing technical inefficiency is one of the main pathways for farms to approach potential production levels. Determinants of technical inefficiency presented in Table 3.

Table 3. Determinants of technical inefficiency in shallot farming in Garut Regency

Variable	Rainy season		Dry season		Pooled model	
	Coef.	t	Coef.	t	Koef.	t
Intercept	0.420	0.510	0.411	0.511	0.360	0.705
Z ₁ Nitrogen residue	0.023	0.826	0.012	0.335	0.026	1.022
Z ₂ Plant density	-0.105	-1.115	0.080	**2.155	-0.013	-0.391
Z ₃ Mechanization	-0.215	*-2.444	-0.844	**2.160	-0.316	**2.269
Z ₄ Farmer age	0.136	0.614	-0.020	-0.099	0.083	0.644
Z ₅ Farming experience	-0.162	**3.133	-0.115	*-1.903	-0.130	**2.797
Z ₆ Farmer group membership	-0.134	*-2.769	-0.025	-0.194	-0.160	-1.307
Z ₇ Extension participation			-0.010	-0.083	-0.124	-1.037
Z ₈ Land tenure status			-0.222	**2.040	-0.115	-1.026
<i>Sigma-squared</i> (σ^2)	0.044	**5.276	0.011	**2.699	0.034	**5.026
<i>Gamma</i> (γ)	0.026	0.016	0.927	**21.813	0.058	0.275
<i>LR-test</i>		9.835		**44.139		**18.787

Note: ** significant at $\alpha = 5\%$ (0.05), * $\alpha = 10\%$ (0.10)

The likelihood-ratio test during the rainy season yielded a value of 9.835, which is lower than the Kodde & Palm (1986) critical value of 14.853 at the 5% significance level. This indicates that variation in shallot output during the rainy season was driven primarily by random noise rather than managerial inefficiency. Such random variation may reflect weather conditions, pest and disease attacks, and other external factors. Accordingly, the coefficients of the

inefficiency effects model for the rainy season should be interpreted as indicative associations or trends rather than strong determinants or causal relationships. In contrast, in the dry season and the pooled model were 44.139 and 18.787, respectively, both exceeding the critical value. This indicates that technical inefficiency effects were statistically relevant. The gamma parameter (γ) represents the proportion of the composite-error variance attributable to technical

inefficiency relative to random noise. The estimates indicate that γ was statistically significant during the dry season but not during the rainy season. The dominance of random noise is not unusual in agricultural production functions because output is strongly affected by uncontrollable environmental factors. Similar finding demonstrated by Waryanto et al. (2014). These findings imply that during the dry season, improvements in farm performance can be pursued primarily through better management, whereas during the rainy season, external factors are more influential, and managerial interventions alone may be insufficient.

Nitrogen residue is an environmental externality associated with excessive nitrogen accumulation in soil from excessive fertilizer application. The analysis indicates that it did not have a statistically significant effect on technical inefficiency. However, the positive coefficient suggests that higher nitrogen residues may reduce technical efficiency and weaken farm performance. Nitrogen is essential for stimulating crop growth and increasing yield, but excessive application beyond crop requirements and safe limits can adversely affect farm performance and the environment. The recommended nitrogen content for shallot production is 250 kg/ha, which was used as the threshold for identifying excess nitrogen residue. Nitrogen residue was calculated as the total nitrogen supplied through all fertilizers minus the recommended amount.

Shallot farms generate nitrogen residues during both seasons. Mean

nitrogen residue was 137.53 kg/ha during the rainy season and 139.10 kg/ha during the dry season. Excessive nitrogen can promote succulent growth, making plants more vulnerable to pest and disease attacks. Soils with excessive nitrogen may also become more acidic, thereby slowing nutrient uptake. Environmental consequences include nitrate contamination of groundwater and ammonia volatilization, which may contribute to acid rain (de Vries, 2021). Accordingly, fertilizer applications should be recalibrated to recommended rates to reduce adverse effects on farm performance and the environment.

Plant density significantly affects farm efficiency during the dry season. Plant density is the number of shallot plants per square meter and is closely related to planting spacing and the quantity of seed used. A higher plant density means narrower spacing and more plants within the same land area, whereas a lower density implies wider spacing and fewer plants. Plant density determines the degree of competition among plants for sunlight, water, and nutrients, thereby affecting growth and yield (Aisyah & Maesaroh, 2025). Higher plant density was associated with lower efficiency, indicating that the number of plants should be reduced to improve efficiency. This finding is consistent with the production-function results in Table 1, where seed use was not statistically significant during the dry season.

Farmers used an average of 1,520 kg of seed/ha. To improve technical efficiency, seed use could be reduced

toward the recommended lower limit of approximately 1,200 kg/ha. Atman et al. (2022) suggested that seed utilization could be optimized through appropriate planting spacing. Optimizing planting distance can improve plant development and yield while reducing seed expenditure and production costs, thereby improving overall farm performance.

Mechanization had a significant effect on shallot farming efficiency during both seasons. The negative coefficients indicate that farmers using mechanical sprayers achieved higher technical efficiency, or lower technical inefficiency. Mechanical sprayers improve pesticide application efficiency in terms of technical performance, time, and labor requirements. Mechanical sprayers generate finer and more uniformly distributed droplets, thereby improving pest-control effectiveness while reducing chemical use. Manual sprayers require greater physical effort and are therefore commonly operated by male laborers, whose wages are relatively high. Mechanical sprayers, by contrast, can also be operated by female workers and reduce the time required for pesticide application. This contributes to lower production costs and more efficient farm operations, strengthening farm performance.

Farmer age did not significantly affect technical inefficiency in any of the estimated models. Age may affect farmers' physical capacity to undertake farm operations. At a certain point, increasing age may reduce physical strength and consequently undermine farming efficiency. However, this effect was not

sufficiently strong to reach statistical significance in the estimated models.

Farming experience in shallot production had a significant effect during both seasons. Although farming experience is generally positively correlated with age, its relationship with technical efficiency was inverse to that of age. Older farmers tend to possess longer farming experience, while increasing age may simultaneously affect physical capacity. However, the estimated coefficients indicate that greater farming experience was associated with lower technical inefficiency.

Experience is an important form of human capital in achieving technical efficiency and profitability (Mariska et al., 2024). Knowledge accumulated through farming practice becomes a basis for managerial decision-making and indirectly enhances farmers' ability to cultivate shallots. More experienced farmers are likely to possess a broader range of practical alternatives and to make more informed decisions. The significant influence of experience on performance was also found in (Nabilla et al., 2025)

Farmer-group membership had a significant effect only during the rainy season. Membership provides several benefits, including access to knowledge through non-formal education, improved managerial capacity, greater access to new technologies, and better opportunities to obtain government support and other forms of assistance. Farmers should therefore be encouraged to participate in active farmer groups.

Participation in agricultural extension activities did not have a statistically significant effect on technical inefficiency. Nevertheless, the negative coefficient indicates that extension participation was associated with improved technical efficiency, although the effect was not statistically significant (Ismail et al., 2017). Farmers who participate in agricultural extension may acquire greater knowledge regarding shallot production and improve farm management.

Land tenure status had a significant effect during the dry season. Its negative coefficient indicates that owner shallot farms were more technically efficient than rented farms. Land ownership creates a stronger sense of control and responsibility, encouraging farmers to manage inputs more effectively in pursuit of maximum output. Land tenure also affects production costs because rented farms incur land-rental expenses. Owner-operated farms do not incur these costs, thereby reducing the total production expenditure associated with shallot farming and improving farm performance.

CONCLUSION

Technical efficiency of shallot farms in Garut Regency differed significantly between the rainy and dry seasons, with mean efficiency scores of 0.931 and 0.844, respectively. The findings indicate that opportunities remain to increase output through improved resource-use efficiency. During the rainy season, output variation was more strongly associated with external

factors, whereas technical inefficiency played a more substantial role during the dry season. The determinants of technical inefficiency also varied across seasons. Mechanization, farming experience, and farmer-group membership were associated with lower inefficiency during the rainy season, while mechanization, farming experience, land ownership, and plant density were more relevant during the dry season. These findings highlight the context-dependent nature of resource effectiveness and the need for season specific management strategies.

During the dry season, interventions should prioritize managerial capacity, resource allocation, cultivation decisions, appropriate mechanization, and optimization of planting density. During the rainy season, greater emphasis should be placed on risk management and farmers' capacity to respond to environmental uncertainty. Strengthening farmer groups, improving access to market and input-use information, and optimizing seed use through appropriate planting distances can further support farm performance.

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