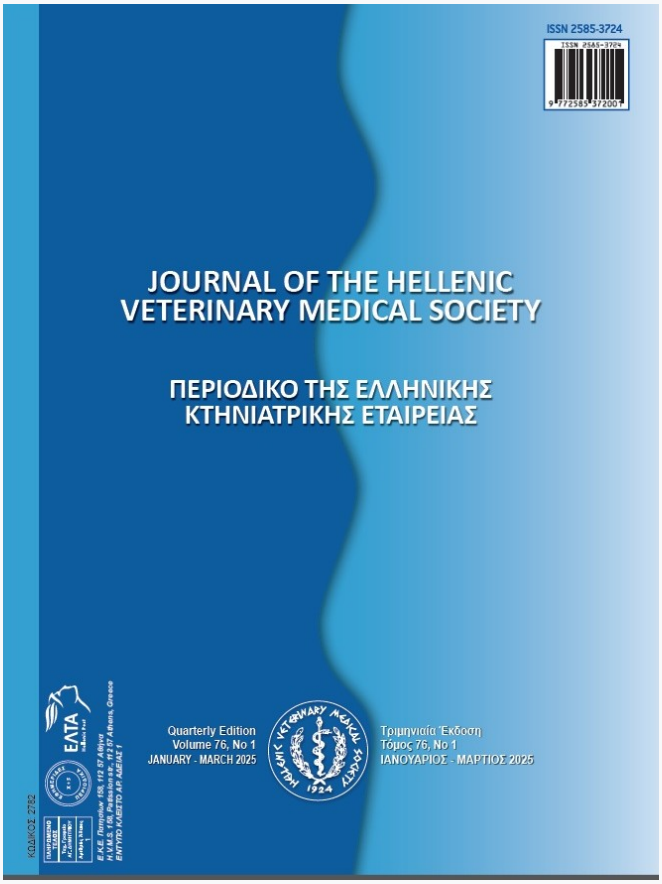
Journal of the Hellenic Veterinary Medical Society

Vol 76, No 1 (2025)



Evaluating Factors Influencing Technical Efficiency and Milk Yield in Dairy Farms: Evidence from the Gaziantep Region, Türkiye

Hİ Tosun

doi: 10.12681/jhvms.38618

J HELLENIC VET MED SOC 2025, 76 (1): 8929-8938
ΠΕΚΕ 2025, 76 (1): 8929-8938

Research article
Ερευνητικό άρθρο

Evaluating Factors Influencing Technical Efficiency and Milk Yield in Dairy Farms: Evidence from the Gaziantep Region, Türkiye

H.I. Tosun*

Rumico Livestock Management and Nutrition, Aydın, Türkiye

ABSTRACT: The dairy industry is a vital component of Türkiye's agricultural sector, contributing significantly to the national economy. This study examines the technical efficiency of dairy farms in the Gaziantep region, a key dairy-producing area in Türkiye, to identify factors influencing milk yield and technical efficiency. Data were collected from 791 dairy farms using stratified random sampling. The study employed the Stochastic Frontier Analysis to estimate efficiency scores, focusing on variables such as feed intake, udder health, and management practices. Technical efficiency scores ranged between 0.65 and 0.99, with an average of 0.95. The coefficients of the variables explaining inefficiency were as expected. By addressing these inefficiencies, milk yield in the region could potentially increase by 5% with the same inputs, improving overall efficiency. The analysis revealed that udder health management practices, including pre-and post-dipping, the use of headlocks after milking, and vaccination programs, significantly impact TE and milk yield (t-values: -2.584, -1.681, and -2.909, respectively). The findings underscore the importance of proper management practices in enhancing the efficiency and productivity of dairy farms. This study provides valuable insights for policymakers, farmers, and researchers aiming to improve dairy farm efficiency and sustainability.

Keywords: Technical efficiency; Milk yield; Dairy farm management; Udder health; Stochastic frontier analysis

Corresponding Author:
Halil Ibrahim Tosun, Rumico Livestock Management and Nutrition, Efeler, 09020, Aydın, Türkiye
E-mail address: halilibrahimtosun@gmail.com

Date of initial submission: 11-08-2024
Date of acceptance: 25-11-2024

INTRODUCTION

The dairy industry is a cornerstone of the agricultural sector in Türkiye, playing a key role in the nation's economic growth (Gürsoy, 2006; Erdem and Ağır, 2024). Efficient dairy production is not only essential for meeting the increasing demand for milk and dairy products but also for sustaining the economic vitality of the dairy sector (Faye and Konuspayeva, 2012; Akbar et al., 2020; Tricarico et al., 2020). To optimize production, it is crucial to understand the factors that influence both milk yield and technical efficiency (TE) across dairy farms. These factors, including feed efficiency, udder health, and management practices, play a significant role in enhancing farm productivity and profitability.

Gaziantep (TRC1), a prominent dairy farming region in Türkiye, presents a unique opportunity to explore these factors, given its wide variety of farm sizes and management systems. TE, which measures the amount of output (milk) generated per unit of input, serves as a key indicator of farm efficiency (Russell and Young, 1983). Farms that operate with higher TE scores are able to produce more milk at lower costs, leading to greater profitability and sustainability (Iribarren et al., 2011).

A crucial aspect of improving TE is optimizing animal nutrition, as feed costs represent a significant portion of a farm's operating expenses (Vandehaar, 1998; Ferrazza et al., 2020; Atzori et al., 2021). In addition to feed efficiency, factors such as animal health, management practices, and environmental conditions also influence TE outcomes (Cabrera et al., 2010; Pulina et al., 2020; Terry et al., 2020; Birhanu et al., 2021). Among these factors, udder health stands out as a critical determinant of both milk yield and farm efficiency. Poor udder health can drastically reduce milk production and quality, resulting in lower TE and financial losses for dairy farmers (Van Soest et al., 2016; Hogeveen et al., 2019; Malik et al., 2018; Skevas and Cabrera, 2020; Neculai-Valeanu and Ariton, 2022).

Several management practices are essential for maintaining udder health and improving overall TE on dairy farms. For example, providing clean and comfortable environments for cows, particularly after calving, helps reduce stress and disease incidence, which in turn enhances TE (Espadamala et al., 2016; Witkowska and Ponieważ, 2022). Additionally, the use of headlocks after milking for activities such as heat detection, insemination, and health checks helps to streamline labor processes while ensuring cows remain standing until their teats close, which reduces the risk of pathogen entry (Papinchak et al., 2022; König et al., 2023; Sorathiya, 2024). Proper bedding practices are also important, as they reduce the risk of udder infections by providing a dry and clean surface, which supports overall cow comfort and health (Robles et al., 2020; Singh et al., 2020; Robles et al., 2021; Zigo et al., 2021). Pre- and post-milking teat dipping is another critical practice that helps prevent mastitis and improves both milk yield and TE by reducing pathogen entry into the udder (Romero et al., 2020; Yanuartono et al., 2020; El-Sayed and Kamel, 2021). Furthermore, vaccination programs that prevent diseases harmful to milk production are essential for maintaining farm efficiency (Chen et al., 2021; El-Sayed and Kamel, 2021; Zigo et al., 2021; Neculai-Valeanu and Ariton, 2022).

This study aims to examine how udder health, TE, and milk yield vary across farms of different sizes (Skevas and Cabrera, 2020; Gantner et al., 2024) and management practices (McMullen et al., 2021; Neculai-Valeanu and Ariton, 2022). The findings will provide valuable insights into the factors that drive dairy farm productivity in Türkiye, offering guidance for policymakers, farmers, and researchers seeking to enhance the efficiency and sustainability of dairy farming in the region.

MATERIALS AND METHODS

Study Area and Data Collection

The research was conducted in the TRC1 region, the largest agricultural production zone in Türkiye's Southeastern Anatolia Region (Figure 1). This region is home to approximately 388,000 cattle, representing about 3% of Türkiye's total dairy cattle population (TUİK, 2020). Data were gathered through surveys conducted during the 2019-2020 production period. In addition to survey data, information from previous studies and records from relevant institutions and organizations was utilized to support the research.

Sampling Method

A stratified random sampling technique was employed to select the dairy farms for the study. Specifically, the Neyman method, a form of stratified random sampling, was used to determine the number of farms to be surveyed. Farms were selected based on their cattle population, with larger farms representing a greater proportion of the sample. This method

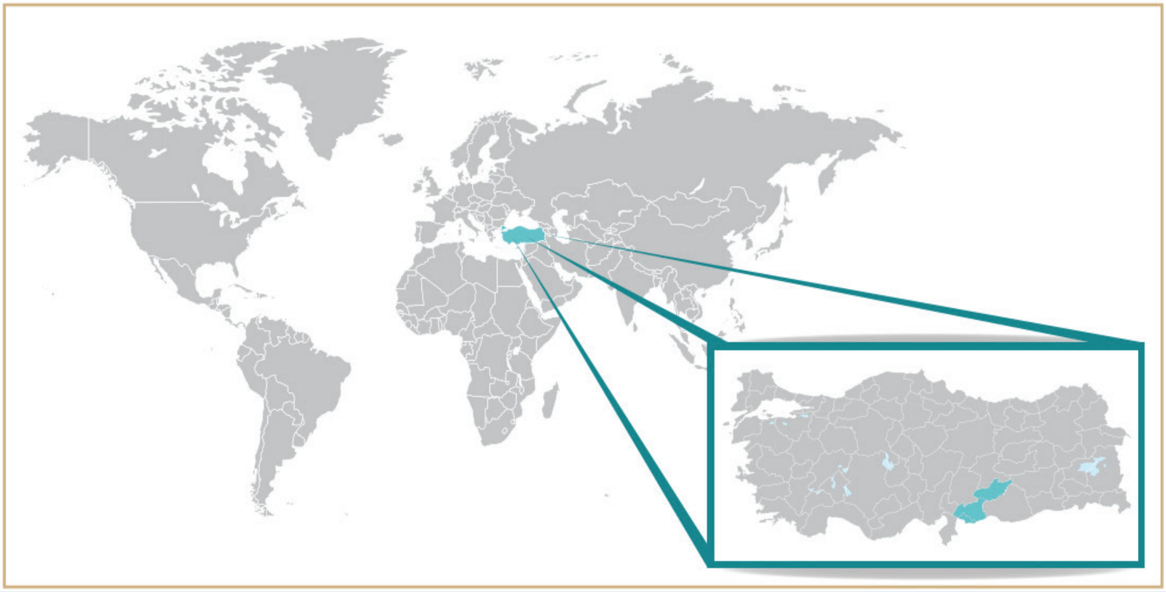


Figure 1. Geographical Location of Study Area in the Gaziantep (TRC1) Region of Türkiye

ensures that the sample reflects the diversity of farm sizes in the region.

The sample size was calculated to ensure statistical reliability with a 5% margin of error and a 99% confidence level. Based on the formula provided by Yamane and Esin (2010), it was determined that 145 farms should be surveyed. The formula for sample size calculation is as follows:

$n=$¿¿¿

In this formula, n represents the number of farms to be surveyed, N denotes the total number of farms in the population, N_h indicates the number of farms in each stratum, S_h is the standard deviation within each stratum, and D represents the allowable margin of error.

The sample size within each stratum was allocated based on the standard deviation using the formula:

$$n_h=\frac{N_h S_h}{\sum N_h S_h}\times n$$

In this formula, n_h represents the sample size allocated to stratum h, N_h is the number of farms in stratum h, S_h is the standard deviation of the stratum, and n represents the total sample size.

Estimation of technical efficiency

The Stochastic Frontier Approach (SFA) was used to estimate TE in this study, following the methodology outlined by Coelli et al. (2005). SFA is an econometric technique that separates the effects of random variation from those caused by inefficiency in production. The analysis was carried out in two stages: In the first stage, TE scores were estimated for each dairy farm using the production function. In the second stage, the relationship between various influencing factors (such as management practices) and technical inefficiency (1-TE) was examined using maximum likelihood estimation.

The production function used in this analysis was based on the model proposed by Aigner et al. (1977) and Meeusen and van Den Broeck (1977). The dependent variable in this function was the 4% fat-corrected milk (FCM) produced per cow per day (kg/day/head). The independent variables included factors such as the number of lactations, days in milk, dry matter intake (kg/day/head), shelter area (m²/head), and labor input (hours/head).

The general form of the stochastic production function used in this study is as follows:

$$Y_i=\beta X_i+v_i-u_i$$

$$v_i-u_i=\varepsilon_i$$

In these equations, Y_i denotes the 4% FCM, X_i stands for the input vector involved in milk production, β represents the unknown parameter, v_i is the stochastic error term (random noise), and u_i is the non-negative term reflecting technical inefficiency.

The term u_i represents the deviation of a farm's performance from the "frontier" of best possible production, while v_i captures random factors like weather or measurement errors.

The Maximum Likelihood Estimation (MLE) method, also known as the Log-Likelihood Function, was used to estimate the unknown parameters. The log-likelihood function used in this study is given by:

$$\ln(L) = \frac{-N}{2}\ln\left(\frac{\pi}{2}\right) - \frac{N}{2}\log\left(\sigma_s^2\right) + \sum_{i=1}^{N} ¿¿$$

$$z_i = \frac{(\ln y_i - x_i\beta)}{\sigma_s}\sqrt{\frac{\gamma}{1-\gamma}}$$

In these equations, L denotes the likelihood function, ϕ (.) represents the cumulative distribution function of the standard normal distribution, γ is the variance parameter associated with inefficiency, σ_s is the total variance parameter of the error term, y_i is the observed milk production, and x_i is the vector of input variables.

Analysis of Technical Inefficiency

A three-stage process was used to estimate the technical inefficiency. First, the coefficients (β) and variance parameters (σ_s²) were estimated using the ordinary least squares (OLS). In the second stage, a one-way likelihood ratio (LR) test was conducted to evaluate the presence of technical inefficiency. This test, based on the recommendations of Coelli (1995), compared the fit of the stochastic frontier model to a model without inefficiency. A chi-squared value of 5.138 (Kodde & Palm, 1986) was used as the critical threshold. At the last stage, optimal parameter estimates were obtained using the iterative Davidon-Fletcher-Powell (DFP) maximization method. The standard errors of the parameter estimates were calculated from the variance-covariance matrix of the final DFP iteration.

The Cobb-Douglas production function was chosen as the most appropriate model, as the LR test statistic was below the critical threshold (LR < χ^2).

The TE scores were then calculated using the following formula:

[TEi = exp(-Ui)]

Where Ui represents the unobservable technical inefficiency. To estimate the average TE across all farms, the following equation was used:

$$E[\exp(-Ui)] = 2¿$$

The TE scores were categorized into three groups: low, medium, and high efficiency, using k-means clustering analysis.

Analysis of factors affecting technical efficiency

To explore the relationship between farm management practices and technical inefficiency, a regression model was developed. The dependent variable was technical inefficiency, defined as 1−TE. This measure quantifies the extent to which a farm deviates from optimal TE.

The regression model for technical inefficiency is expressed as:

$$Mit = Zit\,\delta$$

In this equation, Mit represents the technical inefficiency score for dairy farm i at time t, Zit is a vector of independent variables, and δ denotes the parameter vector to be estimated.

The independent variables considered were management practices hypothesized to affect farm efficiency, including: Fresh Pen (providing a clean, comfortable environment for cows immediately after calving), Lock Up (using headlocks after milking to prevent pathogen entry and ensure udder health), Bedding (offering a dry, clean surface to improve cow comfort and health), Dipping (applying pre- and post-milking teat dips to reduce the risk of infection), and Vaccination (implementing vaccination programs to prevent disease outbreaks).

These management practices were selected based on their potential to reduce inefficiency and improve farm performance.

Comparative analyses

For normally distributed continuous variables, One-Way Analysis of Variance (ANOVA) was used to compare differences between groups. For discrete variables, the Kruskal-Wallis H test was applied. The Chi-Square test was used for categorical variables, and t-tests and Mann-Whitney U tests were used for pairwise comparisons, depending on the data distribution.

All statistical analyses were performed using IBM SPSS Statistics version 20, with a significance level set at $P < 0.05$.

RESULTS

Overview of dairy farms attributes

Table 2 presents the general attributes of the sample dairy farms in Gaziantep region. The mean number of dairy cattle per farm is 47.65±7.35, while the mean number of lactating cows is 26.94±3.97. Annual milk production averages 149.44±25.98 tons. The mean lactation number is 3.81±0.13. On average, cows have 195.10±6.15 days in milk. Daily dry matter intake per cow averages 18.78±0.18 kg. Shelter area per cow averages 7.96±0.50 square meters. The labor force per cow is, on average, 0.07±0.03 persons. Additionally, the average milk yield, adjusted to 4% FCM, is 17.10±0.47 kg per cow daily.

Production function and technical efficiency of dairy farms

Table 3 displays the parameter estimates of the production function, including coefficients, standard errors, and t-values for each variable. Significant factors are marked with asterisks: *$p < 0.10$, **$p < 0.05$, and ***$p < 0.01$.

The findings of the likelihood-ratio test suggested that the production function was stochastic and that a deterministic one was inappropriate for the study data. The gamma value showed that milk output was impacted by technical inefficiencies on dairy farms. Every variable in the stochastic production frontier had predicted signs, according to the maximum likelihood estimation of the production frontier. The milk output per cow was positively impacted by the coefficients of variables including labor, shelter area, and dry matter intake. In the sample dairy farms, a 1% increase in dry matter intake could lead to a 0.26% increase in milk production (Table 3).

A negative correlation between the number of lactation cycles and milk production was discovered using the MLE parameter estimate. The research area's dairy cattle farms with varying lactation numbers saw a decrease in their average milk yield per cow ($p < 0.01$). In the sample dairy farms, there was a 1.591% decline in milk output for every 1% increase in the number of lactations (Table 3).

The flexibility of dry matter intake was assessed to be the second highest, after labor and lactation number. The least elastic variable was "days in milk" ($p > 0.10$). The total of the elasticities revealed that the sample dairy farms had growing returns to scale, suggesting potential for farm scale expansion in the study region (Table 3).

Table 4 presents the TE scores for dairy farms classified into low, medium, and high- efficiency categories, as well as for the overall research cohort in

Table 1. Allocation of Dairy Farms for Survey Across Strata

Stratums (Animal no)	Population	Mean	Standard Err.	Sample Size
First stratum (01 - 30)	370	23.69	2.87	68
Second stratum (31 - 100)	307	47.06	17.30	56
Second stratum (101 - 101+)	114	305.18	219.11	21
Total	791	73.33	127.15	145

Table 2. The General Attributes of the Sample Dairy Farms in Gaziantep Region

Variable	Mean	Std Dv.
Number of dairy cattle	47.65	7.35
Number of lactating cows	26.94	3.97
Milk production (tons/year)	149.44	25.98
Lactation number	3.81	0.13
Days in milk	195.10	6.15
Dry matter intake (kg/d/cow)	18.78	0.18
Shelter areas (m^2/cow)	7.96	0.50
Labor force (person/cow)	0.07	0.03
Milk yield (4% FCM) (kg/d/cow)	17.10	0.47

Table 3. Maximum Likelihood Estimates of Cobb-Douglas Type Production Function

Variables	Coefficient	SE	t-value
Intercept	21.030	3.380	6.221 ***
Lactation number	-1.591	0.265	-5.997 ***
Days in milk (DIM)	-0.008	0.005	-1.519
Dry matter intake (DMI) (kg/d/cow)	0.260	0.156	1.662 *
Shelter area (m^2/cow)	0.161	0.052	3.071 ***
Labor (hour/cow)	4.043	1.044	3.872 ***
Sigma-squared	6.934	0.828	8.369 ***
Gamma	0.068	0.030	2.249 **
Log likelihood		-344.516	
LR		45.445 ***	

*, **, *** denote statistical significance at the 10%, 5%, and 1% probability levels, respectively, for the mentioned variable.

Table 4. Technical Efficiency Scores by Farm Efficiency Category

Variables	Farms	N	Mean	Min	Max
Technical efficiency	Low	92	0.93±0.07^{a}	0.65	0.99
	Medium	49	0.97±0.02^{b}	0.90	0.99
	High	4	0.98±0.01^{b}	0.97	0.99
	TRC1	145	0.95±0.06	0.65	0.99

a,b Values within a row with different superscripts differ significantly at p<0.05

the Gaziantep region. The TE scores were observed to be significantly different across the efficiency categories ($p < 0.05$). Specifically, dairy farms categorized as high efficiency demonstrated the highest mean TE score of 0.98±0.01, with a range from 0.97 to 0.99. Medium efficiency farms followed with a mean score of 0.97±0.02, ranging from 0.90 to 0.99. Low-efficiency farms had the lowest mean TE score at 0.93±0.07, with a range from 0.65 to 0.99. Overall, the Gaziantep cohort had a mean TE score of 0.95±0.06, with scores spanning from 0.65 to 0.99. The results indicate that higher efficiency categories consistently show better TE scores compared to lower efficiency categories, with significant differences between them.

Factors affecting technical efficiency

The maximum likelihood estimates for the parameters related to factors determining technical inefficiency in dairy farms are presented in Table 5. This includes coefficients, standard errors, and t-values for each variable. Significant factors are marked with asterisks, with *$p < 0.10$, **$p < 0.05$, and ***$p < 0.01$ indicating the levels of significance.

Several of the factors examined were found to significantly impact technical inefficiencies in dairy farming operations. For instance, providing a clean and comfortable environment for cows immediately after calving—referred to as fresh pen and bedding—aims to enhance cow comfort and overall health. These variables showed negative coefficients (-2.919 and -2.759, respectively), but their effects were statistically insignificant, as indicated by their t-values (-1.035 and -1.129, respectively) (Table 5).

On the other hand, the variable "lock up," which involves using headlocks after milking to prevent pathogen entry to udders, exhibited a negative coefficient of -3.498 and a t-value of 1.681*, suggesting a potential association between lock-up practices and increased technical inefficiency (Table 5). Additionally, pre- and post-milking teat dipping, as well as regular vaccination procedures, revealed significant negative coefficients (-5.128 and -2.764, respectively), indicating a strong influence on reducing technical inefficiency, as supported by their t-values (-2.584*** and -2.909***, respectively) (Table 5).

DISCUSSION

The findings from this study indicate critical factors influencing TE in dairy farms within the Gaziantep region of Türkiye, providing valuable insights into how different farm management practices impact milk production and overall farm profitability. The results support the theory that the role of udder health and effective management practices in enhancing TE

Table 5. Maximum Likelihood Parameter Estimates (Technical Inefficiency Determinants)

Variables	Coefficient	SE	t-value
Fresh pen (0=No, 1=Yes)	-2.919	2.819	-1.035
Lock up (0=No, 1=Yes)	-3.498	2.081	-1.681 *
Bedding (0=No, 1=Yes)	-2.759	2.443	-1.129
Dipping (0=No, 1=Yes)	-5.128	4.119	-2.584 ***
Vaccination (0=No, 1=Yes)	-2.764	0.950	-2.909 ***
Log likelihood		-429.231	
LR		8.009 ***	

*, **, and *** indicate statistical significance at the 10%, 5%, and 1% probability levels, respectively.

and milk yield aligns with the established literature that emphasizes the close relationship between animal health, nutrition, and economic efficiency in dairy operations (Cabrera et al., 2010; Pulina et al., 2020; Terry et al., 2020; Birhanu et al., 2021).

Based on the results of the efficiency analysis, TE scores varied between 0.65 and 0.99, with an average score of 0.95. The coefficients of the variables explaining the inability to reach the efficient production level were as expected. By eliminating the technical inefficiencies, milk yield can be increased by 5% using the same regional inputs. These findings are consistent with previous studies and suggest that TE varies depending on herd management strategies (Skevas and Cabrera, 2020).

In line with the studies ,one of the most notable observations from the study is the variability in TE scores across different farm sizes and management practices (Skevas and Cabrera, 2020; Gantner et al., 2024). This variability indicates that while some farms operate close to their optimal efficiency, others have substantial room for improvement. The lower TE scores observed in some farms may be attributed to suboptimal management practices, particularly in areas related to udder health management. These include inadequate post-milking care, insufficient providing of clean bedding, and lapses in vaccination and disease prevention protocols.

Such practices are critical in preventing mastitis and other udder-related health issues, which are known to negatively impact milk yield and increase production costs, as documented in previous studies (Chen et al., 2021; Neculai-Valeanu and Ariton, 2022). The study highlights the effectiveness of specific management interventions in improving TE in dairy farming.

Drawing on findings from similar studies (McMullen et al., 2021; Neculai-Valeanu and Ariton, 2022), a more plausible explanation emerges. For example, the use of headlocks post-milking is associated with higher TE scores, likely due to their role in preventing pathogen entry into the udder by ensuring cows remain standing until their teats close (Papinchak et al., 2022; König et al., 2023; Sorathiya, 2024). Additionally, providing fresh pens for cows post-calving and consistently using pre- and post-milking teat dips were correlated with higher efficiency scores. These practices not only enhance udder health but also contribute to better milk quality and higher yields, underscoring the critical role of comprehensive health management in dairy farming as highlighted in previous studies (Romero et al., 2020; Yanuartono et al., 2020; El-Sayed and Kamel, 2021).

The regression model analysis suggests that farm size and the level of management practices are significant determinants of TE. The data clearly show that larger farms with more sophisticated management practices tend to achieve higher efficiency levels, likely due to economies of scale and more effective resource utilization. In contrast, smaller farms with less advanced management practices often struggle to maintain high efficiency, which can lead to lower profitability.

This experiment offers new insights into the relationship between farm size, management practices, and TE. These results should be considered when developing strategies to enhance efficiency in the dairy industry. This finding indicates that targeted interventions, such as training programs and the adoption of best practices, could help smaller farms improve their efficiency and competitiveness within the industry.

This study presents several limitations that should be considered when interpreting the findings. First, the data collection was constrained to the 2019-2020 production cycle, which may not fully capture seasonal or long-term variations in dairy farm productivity and efficiency. Additionally, while the study employed a stratified random sampling method to select dairy farms, the sample size of 145 farms may not fully represent the entire dairy farming population in the region, potentially introducing sampling bias.

The use of the SFA to estimate TE is limited by the assumptions inherent in this method, such as the normal distribution of the stochastic error term and the exclusion of non-measured factors that may impact efficiency. The study's reliance on historical data and self-reported survey responses could introduce inaccuracies or reporting biases. Furthermore, the cross-sectional nature of the data means that causal relationships between factors affecting TE and milk yield cannot be definitively established.

The analysis also assumes that the Cobb-Douglas production function is the most appropriate model for the data, which may not account for all forms of production technology or functional forms. Future research should address these limitations by incorporating longitudinal data, expanding the sample size, exploring alternative efficiency estimation methods, and considering additional variables that may influence dairy farm performance.

CONCLUSIONS

This study provides empirical evidence that improving udder health and adopting effective management practices are crucial for enhancing TE and milk production in dairy farms. The findings highlight the need for continued focus on health management and the adoption of best practices to ensure the sustainability and profitability of dairy farming in the Gaziantep region. Policymakers and industry stakeholders should consider these factors when designing programs aimed at improving the efficiency and productivity of the dairy sector in Türkiye. Further research could explore the long-term impacts of these practices on farm profitability and their applicability across different regions and farm sizes.

ACKNOWLEDGEMENTS

Rumico Livestock Management and Nutrition (RUMICO) has funded this study.

CONFLICT OF INTEREST

The author/s declared that there is no conflict of interest.

REFERENCES

Aigner D, Lovell C K, Schmidt P (1977) Formulation and estimation of stochastic frontier production function models. Journal of econometrics 6(1):21-37. doi: 10.1016/0304-4076(77)90052-5

Akbar M O, Shahbaz Khan M S, Ali M J, Hussain A, Qaiser G, Pasha M, Pasha U, Missen M S, Akhtar N (2020) IoT for development of smart dairy farming. Journal of Food Quality 2020(1):4242805. doi: 10.1155/2020/4242805

Atzori A, Valsecchi C, Manca E, Masoero F, Cannas A, Gallo A (2021) Assessment of feed and economic efficiency of dairy farms based on multivariate aggregation of partial indicators measured on field. Journal of Dairy Science 104(12):12679-12692. doi: 10.3168/jds.2020-19764

Birhanu M Y, Alemayehu T, Bruno J E, Kebede F G, Sonaiya E B, Goromela E H, Bamidele O, Dessie T (2021) Technical efficiency of traditional village chicken production in Africa: Entry points for sustainable transformation and improved livelihood. Sustainability 13(15):8539. doi: 10.3390/su13158539

Cabrera V E, Solis D, Del Corral J (2010) Determinants of technical efficiency among dairy farms in Wisconsin. Journal of Dairy Science 93(1):387-393. doi: 10.3168/jds.2009-2307

Chen Y, Wang Y, Robertson I D, Hu C, Chen H, Guo A (2021) Key issues affecting the current status of infectious diseases in Chinese cattle farms and their control through vaccination. Vaccine 39(30):4184-4189. doi: 10.1016/j.vaccine.2021

Coelli T J (1995) Estimators and hypothesis tests for a stochastic frontier function: A Monte Carlo analysis. Journal of Productivity Analysis 6:247-268. doi: 10.1007/BF01076978

Coelli T J (1996) A guide to FRONTIER version 4.1: A computer program for stochastic frontier production and cost function estimation, CEPA working papers.

Coelli T J, Rao D S P, O'Donnell C J, Battese G E (2005) An introduction to efficiency and productivity analysis. Springer science & business media.

El-Sayed A, Kamel M (2021) Bovine mastitis prevention and control in the post-antibiotic era. Tropical animal health and production 53:1-16. doi: 10.1007/s11250-021-02680-9

Erdem M, Ağır H B (2024) Enhancing dairy farm welfare: A holistic examination of technology adoption and economic performance in Kahramanmaraş province, Turkey. Sustainability 16(7):2989. doi: 10.3390/su16072989

Espadamala A, Pallarés P, Lago A, Silva-del-Río N (2016) Fresh-cow handling practices and methods for identification of health disorders on 45 dairy farms in California. Journal of Dairy Science 99(11):9319-9333. doi: 10.3168/jds.2016-11178

Faye B, Konuspayeva G (2012) The sustainability challenge to the dairy sector-The growing importance of non-cattle milk production worldwide. International Dairy Journal 24(2):50-56. doi: 10.1016/j.idairyj.2011.12.011

Ferrazza R d A, Lopes M A, Prado D G d O, Lima R R d, Bruhn F R P (2020) Association between technical and economic performance indexes and dairy farm profitability. Revista Brasileira de zootecnia 49:e20180116. doi: 10.37496/rbz4920180116

Gantner V, Jožef I, Samardžija M, Steiner Z, Gantner R, Solić D, Potočnik K (2024) The variability in the prevalence of subclinical and clinical mastitis and its impact on milk yield of Holstein and Simmental cows as a result of parity. Veterinarski Arhiv 94(4):269-284. doi: 10.24099/vet.arhiv.2518

Gürsoy O (2006) Economics and profitability of sheep and goat production in Turkey under new support regimes and market conditions. Small ruminant research 62(3):181-191. doi: 10.1016/j.smallrumres.2005.08.013

Hogeveen H, Steeneveld W, Wolf C A (2019) Production diseases reduce the efficiency of dairy production: A review of the results, methods, and approaches regarding the economics of mastitis. Annual review of resource economics 11(1):289-312. doi: 10.1146/annurev-resource-100518-093954

Iribarren D, Hospido A, Moreira M T, Feijoo G (2011) Benchmarking environmental and operational parameters through eco-efficiency criteria for dairy farms. Science of the total environment 409(10):1786-1798. doi: 10.1016/j.scitotenv.2011.02.013

Kodde D A, Palm F C (1986) Wald criteria for jointly testing equality and inequality restrictions. Econometrica: Journal of the econometric society:1243-1248. doi: doi.org/10.2307/1912331

König F, Hancock A, Wunderlich C, Klawitter M, Breuer T, Simoni A, Weimar K, Drillich M, Iwersen M (2023) Systematic evaluation of different fresh cow monitoring procedures. Animals 13(7):1231. doi: 10.3390/ani13071231

Malik T A, Mohini M, Mir S, Ganaie B, Singh D, Varun T, Howal S, Thakur S (2018) Somatic cells in relation to udder health and milk quality-a review. Journal of Animal Health and Production 6(1):18-26. doi: 10.17582/journal.jahp/2018/6.1.18.26

McMullen C K, Sargeant J M, Kelton D F, Churchill K J, Cousins K S, Winder C B (2021) Modifiable management practices to improve udder health in dairy cattle during the dry period and early lactation: A scoping review. Journal of Dairy Science 104(9):10143-10157. doi: 10.3168/jds.2020-19873

Meeusen W, van Den Broeck J (1977) Efficiency estimation from Cobb-Douglas production functions with composed error. International Economic Review:435-444. doi: 10.2307/2525757

Neculai-Valeanu A S, Ariton A M (2022) Udder health monitoring for prevention of bovine mastitis and improvement of milk quality. Bioengineering 9(11):608. doi: 10.3390/bioengineering9110608

Papinchak L, Paudyal S, Pineiro J (2022) Effects of prolonged lock-up time on milk production and health of dairy cattle. Veterinary Quarterly 42(1):175-182. doi: 10.1080/01652176.2022.2119622

Pulina G, Tondo A, Danieli P P, Primi R, Matteo Crovetto G, Fantini A, Macciotta N P P, Atzori A S (2020) How to manage cows yielding 20,000 kg of milk: Technical challenges and environmental implications. Italian Journal of Animal Science 19(1):865-879. doi: 10.1080/1828051X.2020.1805370

Robles I, Kelton D, Barkema H, Keefe G, Roy J, Von Keyserlingk M, DeVries T (2020) Bacterial concentrations in bedding and their association with dairy cow hygiene and milk quality. Animal 14(5):1052-1066. doi: 10.1017/S1751731119002787

Robles I, Zambelis A, Kelton D, Barkema H, Keefe G, Roy J, Von Keyserlingk N, DeVries T (2021) Associations of freestall design and cleanliness with cow lying behavior, hygiene, lameness, and risk of high somatic cell count. Journal of Dairy Science 104(2):2231-2242. doi: 10.3168/jds.2020-18916

Romero G, Peris C, Fthenakis G C, Diaz J R (2020) Effects of machine milking on udder health in dairy ewes. Small Ruminant Research 188:106096. doi: 10.1016/j.smallrumres.2020.106096

Russell N P, Young T (1983) Frontier production functions and the measurement of technical efficiency. Journal of Agricultural Economics 34(2):139-150. doi: 10.1111/j.1477-9552.1983.tb00984.x

Singh A K, Kumari T, Rajput M S, Baishya A, Bhatt N, Roy S (2020) A review: Effect of bedding material on production, reproduction and health and behavior of dairy animals. International Journal of Livestock Research 10(7):11-20. doi: 10.5455/ijlr.20200207073618

Skevas T, Cabrera V (2020) Measuring farmers' dynamic technical and udder health management inefficiencies: The case of Wisconsin dairy farms. Journal of Dairy Science 103(12):12117-12127. doi: 10.3168/jds.2020-18656

Sorathiya L M (2024) Association of good dairy farming practices, welfare and performance: A Review. Indian Journal of Animal Production and Management 40(3):134-145

Terry S A, Basarab J A, Guan L L, McAllister T A (2020) Strategies to improve the efficiency of beef cattle production. Canadian Journal of Animal Science 101(1):1-19. doi: 10.1139/cjas-2020-0022

Tricarico J, Kebreab E, Wattiaux M (2020) Sustainability of dairy production and consumption in low-income countries with emphasis on productivity and environmental impact. Journal of Dairy Science 103(11):9791-9802. doi: 10.3168/jds.2020-18269

TUİK (2020) Büyükbaş hayvan saysısı. Türkiye istatistik kurumu. Retrieved 4 June 2020 from https://biruni.tuik.gov.tr/ilgosterge/?locale=tr

Van Soest F J, Santman-Berends I M, Lam T J, Hogeveen H (2016) Failure and preventive costs of mastitis on Dutch dairy farms. Journal of Dairy Science 99(10):8365-8374. doi: 10.3168/jds.2015-10561

Vandehaar M J (1998) Efficiency of nutrient use and relationship to profitability on dairy farms. Journal of Dairy Science 81(1):272-282. doi: 10.3168/jds.S0022-0302(98)75576-6

Witkowska D, Ponieważ A (2022) The effect of housing system on disease prevalence and productive lifespan of dairy herds—A case study. Animals 12(13):1610. doi: 10.3390/ani12131610

Yamane T, Esin A (2010) Temel örnekleme yöntemleri. Literatür yayıncılık.

Yanuartono Y, Nururrozi A, Indarjulianto S, Purnamaningsih H, Ramandani D (2020) The benefits of teat dipping as prevention of mastitis. Journal of Livestock Science and Production 4(1):231-249

Zigo F, Vasil M, Ondrašovičová S, Výrostková J, Bujok J, Pecka-Kielb E (2021) Maintaining optimal mammary gland health and prevention of mastitis. Frontiers in Veterinary Science 8:607311