Technical Efficiency of Yak Milk Producers in Eastern Himalayas: A Stochastic Frontier Analysis Approach

Tenzin Choephel[1], Manmohan Mall[1], Arindam Garg[2], Odang Mara[2]

10.18805/ajdfr.DR-2398

ABSTRACT

Background: Yak herding is a traditional livelihood practiced in the high-altitude regions of Arunachal Pradesh, India, where yak milk serves as a vital source of nutrition and income for pastoral communities. Given the challenging terrain, limited resources and changing climatic and market conditions, assessing the technical efficiency of yak milk production is essential to enhance productivity and improve livelihoods.

Methods: This study employs a Cobb-Douglas stochastic frontier production function to estimate the technical efficiency of 233 yak herders from Tawang and West Kameng districts. Primary data were collected through structured interviews and key input variables included herd size, green and dry fodder, mineral mix and labour hours.

Result: The results revealed that inputs such as herd size, green fodder, dry fodder and concentrates significantly influenced milk yield, while labour input had an insignificant effect. The mean technical efficiency of the sample was estimated at 87.52%, with room for improvement of 12.48% through better input management. Efficiency levels varied across farm sizes and geographic circles, with large herders and those in the Thingbu circle achieving the highest efficiency scores. These findings suggest the need for targeted interventions to enhance productivity and support sustainable yak herding systems in the Eastern Himalayas.

Key words: Pastoral system, Productivity, SFA, Technical efficiency, Yak milk.

INTRODUCTION

Yak herding is a traditional livelihood practiced predominantly in the high-altitude regions of the Himalayas, playing a crucial role in the socio-economic and cultural fabric of indigenous communities (Dorji, 2022). Yaks are valued not only for their resilience in extreme climates but also for their diverse range of products, with yak milk being one of the most significant (Ghatani and Tamang, 2016). Rich in fat, protein and essential nutrients, yak milk serves as a vital source of nutrition and income for herding families through the production of butter, cheese and other dairy products (Dorji, 2022). Changes in the grass composition of pasture according to the seasons led to changes in the chemical composition of their milk, especially fats (higher in winter) and proteins (lower in winter and spring) (Hong-Xin *et al.*, 2023). Given the challenges of climate change, limited pastureland and shifting market dynamics, it is essential to estimate the technical efficiency of yak herding and milk production (Singh *et al.*, 2018). Doing so enables policymakers and stakeholders to identify productivity gaps, optimize resource use and support interventions that enhance income sustainability and food security among pastoral communities (Wangdi and Norbu, 2018). Yak herders heavily rely on yak milk production as a vital source of livelihood, providing essential nutrition and income through raw milk and dairy products. Their pastoral lifestyle and economic sustenance are closely linked to the quantity and quality of milk harvested from their yaks (Melvyn and Cynthia, 1990).

[1]Centre for Management Studies, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar-791 111, Arunachal Pradesh, India.
[2]Department of Management, Rajiv Gandhi University, Itanagar-791 111, Arunachal Pradesh, India.

Corresponding Author: Tenzin Choephel, Centre for Management Studies, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar-791 111, Arunachal Pradesh, India.
Email: choephel1995gmail.com
ORCIDs: https://orcid.org/0009-0000-2870-5537, https://orcid.org/0000-0003-0739-202X, https://orcid.org/0009-0007-9731-432X

How to cite this article: Choephel, T., Mall, M., Garg, A. and Mara, O. (2026). Technical Efficiency of Yak Milk Producers in Eastern Himalayas: A Stochastic Frontier Analysis Approach. *Asian Journal of Dairy and Food Research*. **45(2):** 345-350. doi: 10.18805/ajdfr. DR-2398.

Submitted: 08-09-2025 **Accepted:** 13-11-2025 **Online:** 26-11-2025

MATERIALS AND METHODS

Arunachal Pradesh holds a vital place in yak herding in India, being home to one of the largest yak populations in the country (Rai *et al.*, 2024). Its high-altitude regions, such as Tawang and West Kameng, provide ideal grazing grounds and the practice is deeply intertwined with the livelihoods and culture of local tribal communities. The two westernmost districts of Arunachal Pradesh, Tawang and West Kameng, are home to the majority of Yak herders. Thus, the study's concentration is on these areas. Yak herders from seven circles in Tawang district and one circle in West Kameng district are interviewed according to a

prearranged schedule. Most of the yak herders are primarily Bro-keh native speakers. Using Yamane's sample size estimation formula, 233 sample respondents were estimated, of whom 55 were from the Dirang circle of West Kameng district and 178 were herders from Tawang district. Yak herders were personally given an organised interview schedule in order to gather primary data. The field survey and data collection for this study were conducted between May 2022 and September 2023. The research was undertaken at the Department of Management, Rajiv Gandhi University, Arunachal Pradesh, India. All data collection, tabulation and analyses were conducted under the supervision of the department. The functional form we employed to specify the stochastic production is the Cobb Douglas function. The Cob-Douglas functional form is chosen because the small number of observations makes it impossible to estimate a model with fully flexible functional forms. It is also broadly applied in farm efficiency analysis for both developing and developed countries (Kerorsa and Suk, 2025).

Empirical model of technical efficiency

The Cobb-Douglas stochastic production function is specified as follows:

$$Y = \beta_0 X_1^{\beta 1} X_2^{\beta 2} X_3^{\beta 3} X_4^{\beta 4} X_5^{\beta 5} (Vi\text{-}Ui)$$

Taking the natural logarithms on both sides, the log-linear form of the production function becomes:

$$\ln Y = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + \exp (Vi - Ui)$$

Where,

lnY= Natural logarithm of the daily milk yield per milking yak (in litres).

lnX_1= Natural logarithm of the Herd size (total number of milch yak per farm)

lnX_2= Natural iogarithm of green fodder (in kg).

lnX_3= Natural iogarithm of dry fodder (in kg).

lnX_4= Natural logarithm of concentrates and Mineral mix (in kg).

lnX_5= Natural logarithm of labour hours employed in the farm (in hours)

β_0, β_1, β_2, β_3, β_4 and β_5 = Are unknown parameters to be estimated

(vi - ui) = e = Random error term.

Stochastic frontier analysis (SFA) is a powerful econometric tool used to estimate the technical efficiency of production units, such as yak milk producers, by separating random errors from inefficiency effects (Lakshmipriya *et al.*, 2023). In this study, a Cobb-douglas stochastic production function is employed, where the daily milk yield per milking yak (Y) is modelled as a function of key inputs: herd size, green fodder, dry fodder, concentrate and mineral mix and labour hours. V_i represents statistical noise and, captures technical inefficiency. The benefit of this model is that it enables a single stage estimation technique that can estimate efficiency scores particular to farms as well as the factors causing efficiency differences amongst dairy farmers (Lakshmipriya *et al.*, 2023). This approach allows for a more realistic estimation of efficiency by accounting for both random shocks (such as weather or animal health) and producer-specific inefficiencies, making it highly suitable for analyzing yak milk production in the challenging environments of Arunachal Pradesh. This study focuses on exposing the technical efficiency of yak herders of Arunachal Pradesh in producing yak milk and determining their production efficiency.

RESULTS AND DISCUSSION

Technical efficiency estimates of yak herders

Table 1 illustrates the descriptive statistics of the variables used in the estimation of technical efficiency. An average typical yak Herder in Arunachal Pradesh is 46 years old with an average of 25 years of experience in yak herding and dairy farming activity. An average Yak Herder in the Tawang and West Kameng districts of Arunachal Pradesh is employed for 8 hours a day in yak-rearing activities and produces 31 litres of milk on average per day. The average daily consumption of green fodder, dry fodder and other concentrates and minerals are 16, 6 and 5 kg respectively by the milch animal. The average milch herd size is 16 in the sample. These results show that most of the yaks Herders are well experienced when it comes to yak-rearing. Data on milk yield were self-reported by yak herders during face-to-face interviews using a structured questionnaire. Direct measurement was not feasible given the extensive grazing systems; however, herders provided yield estimates

Table 1: Descriptive statistics of the main characteristics of yak herders.

Variables	N	Minimum	Maximum	Mean	Standard deviation
Milk production (in litres)	233	10	57	31.09	10.478
Milch animal (in numbers)	233	2	73	16.14	10.907
Herders age (in years)	233	21	79	46.15	11.782
Herders experience (in years)	233	4	61	25.12	12.326
Herder's education (in years)	233	1	9	1.83	1.718
Green fodder (in kilogram per milch animal)	233	5	32	16.4421	5.306
Dry fodder (in kilogram per milch animal)	233	0	16	6.313	2.842
Concentrates and minerals (in kilogram per milch animal)	233	1	15	5.841	2.388
Labour (in hours employed on the farm)	233	6	19	8.794	2.280

Source: Field work (2022-2024).

based on their routine milking experience and seasonal records. Milk composition also varies among different breeds, which may be greatly attributed to different chemical composition and feeding value of forages from the swards of grazing lands (Dong *et al.*, 2007). 22.3% of herders produce 31 to 35 liters of milk daily, while 15.5% produce 21 to 25 liters. Only a small fraction (0.9%) exceed 56 liters per day. Although large herders are more common, they produce less milk overall as they primarily milk for cheese and butter, with limited facilities for milk preservation due to their nomadic lifestyle in tents and stone huts (Choephel and Mall, 2024).

Estimation of stochastic frontier production function

The maximum likelihood estimate (MLE) shows the estimation of the technical efficiency using the stochastic production function (Kibara and Kotosz, 2019). From Table 2, the maximum likelihood estimates of the production function of milk production by yak herders in Arunachal Pradesh are made evident. Herd size, quantity of green fodder, dry fodder, concentrates and minerals have a significant influence on the technical efficiency. The coefficient here represents the elasticity of milk production concerning the respective inputs taken. The positive co-efficient indicates the under usage of the particular inputs and the negative co-efficient shows the over usage of the particular inputs by the herders. Efficiency can be improved through the reduction of negative signed co-efficient and can be increased by the additional use of the positive signed co-efficient.

Herd size, the quantity of green fodder, concentrates and other minerals co-efficient values are with positive signs and are significant at a 1% level. The co-efficient value for the quantity of dry fodder is also positive and is significant at a 5% level. Here, a direct relationship is identified which implies that all these factors are important contributors to the improvement of technical efficiency in the milk production of yak herders in Arunachal Pradesh. The statistics imply that anyone per cent increase in herd size, the quantity of green fodder, dry fodder, concentrates and other minerals would result in an increase in milk production by 0.16 per cent, 0.36 per cent, 0.079 per cent and 0.19 per cent for each of these variables respectively. This situation can be defined as a relatively inelastic situation. The relative inelastic situation occurs when a 1 per cent increase in any independent variable, which can cause a less than one per cent increase in the dependent variable. However, the labour hours are not significant and its elasticity is positive. The gamma value of the MLEs of the stochastic frontier production model is 0.571 and is significant at a 1 per cent level implying that 57.15 per cent of the variability in the quantity of milk production of yak herders is attributed to the technical efficiency of milk production. This estimate implies that a significant part of milk production variability among yak Herders can be explained by differences in technical efficiency. The remaining 42.85 per cent variation in milk production is due to random error, those factors have no control over enhancing efficiency. The Generalized Likelihood Ratio (LR) statistic is used for testing the null hypothesis for the absence of inefficiency effects in the cob-Douglas stochastic frontier production function (Baten *et al.*, 2009). The presence of technical inefficiency was tested by the Likelihood Ratio (LR) test in Table 3. The null hypothesis (H_0) implies that the gamma (γ) value is zero. The alternative hypothesis (H_1) explains the gamma (γ) value is different from zero and it shows that the application of the stochastic production frontier is adequate. According to the statistics principle, the null hypothesis will be rejected, if the LR test is greater than the critical chi-square value (Kalirajan and Shand, 1989).

Table 2: Maximum-likelihood estimates of the cobb-douglas production function of the yak herders.

Production function	Parameters	Co-efficient	Standard-Error	t-ratio
Constant	β_0	1.43017	0.15822	9.0391**
Herd size	β_1	0.16263	0.02309	7.0437**
Green fodder	β_2	0.35780	0.05285	6.7699**
Dry fodder	β_3	0.07931	0.03676	2.1572**
Concentrates and other minerals	β_4	0.19739	0.04168	4.7357**
Labour hours	β_5	0.10010	0.06891	1.4525
Inefficiency effects				
Sigma-squared		0.05295	0.01312	4.0361**
Gamma		0.57158	0.21649	2.6401**
LR test off the one side error				1.3630
Log-likelihood function				65.0876

Note: Calculation based on primary data ** significant at 5% level.

Table 3: Result of generalized likelihood test.

Null hypothesis (H_0)	Test statistics (λ)	Critical value (χ^2 .095)	Decision
H_0: $\gamma=\delta_0=\delta_1....\delta_5=0$	1.3630	10.37	Accept H_0

Note: Calculation based on primary data.

The LR value is 1.3630 and the critical chi-square value ($\chi^2_{0.05}$) is equal to 10.37. The LR test value is less than the critical value and it is statistically not significant, which implies that the null hypothesis is accepted (Riedle, Neath and Cavanaugh, 2020). Hence it is right to state that there are no inefficiency effects in the production function and the surveyed Yak Herders in the study area are technically efficient.

Technical efficiency of yak herders

Farm-specific technical efficiencies are important measurement tools in maximising milk production at the farm level. Table 4 shows the frequency distribution of dairy Herders under different levels of technical efficiency of milk production in the study area. The minimum technical efficiency in the sample is 63 per cent whereas, the highest level of technical efficiency attained by the yak Herders is 96 per cent. It is evident through this result that the deviations in the technical efficiency among the yak Herders are limited. 61.4 per cent of the Herders operate with a technical efficiency that ranges between 81 to 90 per cent. 7.3 per cent of Herders operate with a technical efficiency that ranges between 71 to 80 per cent. Only 0.9 per cent of the entire sample size has technical efficiency between 61 to 70 per cent. Around 30.5 per cent of the sample size has achieved technical efficiency between 19 to 100 per cent. The more the technical efficiency, the less the deviation from the production frontier. The mean technical efficiency of the dairy farm producers is 87.52 per cent. There is room for potential improvement in the efficiency level by 12.48 per cent which can be achieved by proper utilization of available input resources. Attaining a high level of efficiency will make the Herders produce the maximum output from their inputs and that will also increase their profit.

Table 4: Deciles range frequency distribution of technical efficiency of the yak herders.

Efficiency level (percentage)	Frequency	Percentage
≤60	0	0
61-70	2	.9
71-80	17	7.3
81-90	143	61.4
91-100	71	30.5
Total	233	100
Mean efficiency		87.52
Minimum efficiency		63
Maximum efficiency		96
Standard deviation (δ)		5.1383

Note: Calculation based on primary data.

Estimation of technical efficiency of different farm sizes

To determine the technical efficiency of the different Herder size categories, the mean of technical efficiency indices of the milk production for different Herders are obtained. The Herders are classified based on their milch animal holding. Table 5 shows the indices of mean technical efficiency of different farm sizes. The mean efficiency of small Herders, medium Herders and large Herders are almost the same (83.68 per cent, 87 and 88.05 per cent, respectively). The medium and large Herders are slightly more efficient than the small Herders when it comes to technical efficiency. The large Herder uses more advanced technologies on their farm so that the labour hours can be reduced. Based on the technical efficiency, the average potential improvement for the technical efficiency of milk production among the different farm sizes is also determined. The average potential for improvement is greater for small Herders (16.32 per cent). The medium and large Herder needs to increase their mean technical efficiency only by 13 per cent and 11.95 per cent respectively. Overall, for all the categories - if the average dairy Herder needs to achieve the technical efficiency level, the Herder needs to improve by 12.48 per cent.

Estimation of technical efficiency of different circles under Tawang and West Kameng district of Arunachal Pradesh

To determine the technical efficiency of the different circles from Tawang and West Kameng District, the mean of technical efficiency indices of the milk production from different circles from the study area are obtained. The indices of the mean technical efficiency of different circles are presented in the above Table 6. The mean efficiency of circles from Tawang District *i.e* Tawang, Kitpi, Lumla, Zemithang, Mukto, Jang, Lhou and Thingbu are 86.50 per cent, 82.65 per cent, 88.44 per cent, 81.09 per cent and 82.07 per cent, 88.28 per cent, 86.31 and 90.06 per cent, respectively. Thingbu circle from Tawang district is found to be more efficient (90.06 per cent) than other circles

Table 5: Mean technical efficiency estimation and increasing efficiency potential of different farm sizes.

Farm size	Minimum technical efficiency	Maximum technical efficiency	Mean technical efficiency	Mean potential to increase technical efficiency
Small herders	62.56	91.69	83.68	16.32
Medium herders	67.82	94.05	87.00	13
Large herders	73.43	96.36	88.05	11.95
Overall	62.56	96.36	87.52	12.48

Note: Calculation based on primary data.

Table 6: Mean technical efficiency estimates and increasing efficiency potential of different circles.

Circle	Minimum technical efficiency	Maximum technical efficiency	Mean technical efficiency	Mean potential to Increase technical efficiency
Tawang	76.35	92.98	86.50	13.50
Kitpi	74.58	89.77	82.65	17.35
Lumla	83.00	90.71	88.44	11.56
Zemithang	62.56	90.12	81.09	18.91
Mukto	75.35	92.99	83.07	16.93
Jang	80.56	93.50	88.28	11.72
Lhou	73.43	93.97	86.31	13.69
Thingbu	73.22	96.36	90.06	9.4
Dirang	77.93	93.58	87.72	12.28

Note: Calculation based on primary data.

Table 7: Mean technical efficiency estimates and increasing efficiency potential of different districts.

Circle	Minimum technical efficiency	Maximum technical efficiency	Mean technical efficiency	Mean potential to increase technical efficiency
Tawang	62.56	96.36	87.46	12.54
West kameng	77.93	93.58	87.72	12.28

Note: Calculation based on primary data.

because most of the households in the villages in the thingbu circle are primarily engaged in yak herding. The villages in Thingbu Circle are Rho, Tsechu, Luguthang, Mago and Thingbu which are known to be the remote villages where the original yak herders inhabit. They usually do not rear the breeds of yak but are engaged in herding the original yak male and female (Choephel, Mall, Mara, Tashi and Mohanty, 2025). The yak Herders from Tawang and other circles usually travel to mago and thingbu villages to buy the yak breeds called dzomo.

Estimation of technical efficiency of Tawang and West Kameng district

To determine the technical efficiency of the Tawang and West Kameng Districts, the mean of technical efficiency indices of the milk production from these two districts area are obtained. Table 7 ilustrates that there is no significant difference between the technical efficiency of the Tawang and West kameng districts. The mean technical efficiency of the Tawang and West Kameng districts is 87.46 per cent and 87.72 per cent, respectively. The minimum technical efficiency in the Tawang district is 62.56 per cent whereas the minimum technical efficiency obtained in the West Kameng district is 77.93 per cent. However, there is room for possible improvement in the technical efficiency. For yak herders in Tawang district, the mean potential to increase the technical efficiency is 12.54 per cent. For yak herders in the West Kameng district, the mean potential to increase technical efficiency is 12.28 per cent.

CONCLUSION

This study evaluated the technical efficiency of yak milk producers in Arunachal Pradesh, revealing an average efficiency of 87.52% with room for improvement. Key inputs like herd size and fodder significantly influenced production, while labor had little impact. Efficiency varied by farm size and location, highlighting the need for targeted support. Policy measures including improved input access, training, breed conservation and infrastructure development are essential to enhance productivity and sustain livelihoods of yak herders in the Eastern Himalayas. Collaborative efforts involving government, researchers and local communities will be crucial to promote sustainable yak farming practices and improve market access for yak dairy products. Continued research and innovation will further strengthen resilience and economic viability in this traditional sector.

ACKNOWLEDGEMENT

We are grateful for institutional support provided by Centre for Management Studies, North Eastern Regional Institute of Science and Technology for providing necessary support. Further, I would like to express my sincere gratitude to all the yak herders who participated in providing valuable information during the field work.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are

responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

REFERENCES

Baten, M.A., Kamil, A.A. and Haque, M.A. (2009). Modeling technical inefficiencies effects in a stochastic frontier production function for panel data. *African Journal of Agricultural Research.* **4(12):** 1374-1382.

Choephel, T., Garg, A. and Mall, M. (2024). Yak Milk Production in North-East India: Prospect of Yak Herding in Arunachal Pradesh. *Indian Journal of Animal Pduction and Management*. 237-242 .

Choephel, T., Mall, M., Mara, O., Tashi, T. and Mohanty, M.K. (2025). Traditional feeding practices of brokpas in Arunachal Pradesh: A case study on estimating economic eficiency of yak herders in Northeast India. *Research on World Agricultural Economy.* **6(4):** 513-525.

Dong, S., Long, R. and Kang, M. (2007). Milking performance of China yak (*Bos grunniens*): A preliminary report. *African Journal of Agricultural Research.* **2(3):** 52-57.

Dorji, W. (2022). The future of yak farming and herding culture in Bhutan: A case of the Brokpa herders of Merak and Sakteng. *Culture, Agriculture, Food and Environment*. pp. 110-119.

Ghatani, K. and Tamang, B. (2016, 04). Indigenous rearing practices of Yak and its multipurpose uses in the Sikkim Himalayas. *Journal of Agriculture and Veterinary Science.* **9:** 1-8.

Hong-Xin, J., Mi-Ya, S. and Wen-Liang, C. (2023). Chemical and Fatty acids composition of yak milk from qinghai-tibetan plateau in different seasons. *Indian Journal of Animal Research*. 1-6. doi: 10.18805/IJAR.BF-1678.

Kalirajan, K.P. and Shand, R.T. (1989). A generalized measure of technical efficiency. *Appl. Econ.* **21:** 2-34.

Kerorsa, G.M. and Suk, K.G. (2025). Factors affecting technical efficiency of urban dairy farming: The case of Nekemte City, Oromia, Ethiopia. *Agricultural Reviews*. 1-9. doi: 10.18805/ag.RF-323.

Kibara, M.J. and Kotosz, B. (2019). Estimation of stochastic production functions: The state of the art. *Hungarian Statistical Review*. pp. 57-89.

Lakshmipriya, P., Sinha, D.K., Singh, K.M., Ahmad, N., Raju, R. and Roy, A. (2023). Profit efficiency among dairy farmers in Southern India: An application of stochastic frontier profit function. *Indian Journal of Animal Research*. 1-7. doi: 10.18805/IJAR.B-5096.

Melvyn, G.C. and Cynthia, B.M. (1990). Nomads of Western Tibet: The Survival of a Way of life. Los Angeles: University of California Press.

Rai, R.K., Joshi, S., Dorji, T. and Pant, B. (2024). Herders' preferences for maintaining yak herding in the Eastern Himalayas. *Rangeland Ecology and Management.* **94:** 20-28.

Riedle, B., Neath, A.A. and Cavanaugh, J.E. (2020). Reconceptualizing the p-value from a likelihood ratio test: A probabilistic pairwise comparison of models based on Kullback-Leibler discrepancy measures. *Journal of Applied Statistics*. pp 2582-2609.

Singh, R.K., Sureja, A.K. and Maiti, S. (2018). Grazing and rangeland management: Trans-human adaptations by Brokpa community in fragile ecosystems of Arunachal Pradesh. *Indian Journal of Traditional Knowledge.* **17(3):** 550-558.

Wangdi, S. and Norbu, N. (2018). Good fences are key to sustainable pasture management and harmonious pastoral society of Merak and Sakteng in Bhutan. *Pastoralism: Research, Policy and Practice*.