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ARTICLE

Traditional Feeding Practices of Brokpas in Arunachal Pradesh: A Case Study on Estimating Economic Efficiency of Yak Herders in Northeast India

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ABSTRACT

Yak Herding plays a significant role in the livelihoods of high-altitude pastoral communities in Arunachal Pradesh, India. This study aims to analyze the influence of traditional feeding strategies on yak health, milk yield, production, and overall economic efficiency. The highland pastoralist communities are dependent on the natural grazing for their animal, which is a sustainable and cost-effective way of livelihood. Despite facing multiple challenges concerning feed management. The research is based on field observations, surveys, and interviews with yak herders to analyze traditional and modern feeding practices followed by the yak herders in remote areas of Arunachal Pradesh. The study highlights the need for sustainable feeding strategies to ensure better productivity, economic viability, and resilience against climatic challenges. Proper feeding practices, including supplementary feeding during winter and improved pasture management, significantly enhance milk production, reproductive performance, and yak survival rates. Findings indicate that at the 0.05 level of significance, the labour cost coefficient

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and the concentrate and mineral cost coefficient both show positive trends and are statistically significant. The positive coefficient means that the cost of producing milk will increase by 0.0287 per cent for every per cent increase in concentrate and mineral prices. In a similar vein, the positive labour cost coefficient suggests that a per cent rise in labour costs will result in a 0.062 per cent increase in milk production costs. Recommendations include the adoption of balanced nutrition plans, fodder conservation techniques, and policy support for improving feed availability. The findings contribute to the broader understanding of efficient yak farming practices in Arunachal Pradesh and their implications for pastoral sustainability.

Keywords: Yak Herding; Feeding Practices; Sustainability; Economic Efficiency; Livestock Management

1. Introduction

Yak Herding is an essential component of pastoral livelihoods in Arunachal Pradesh, providing milk, meat, wool, and draught power. However, traditional feeding practices, climate variability, and limited access to nutritious fodder pose challenges to productivity. In many places where a particular society herds yaks to provide necessities like milk, cheese, butter, meat, hair, etc., yaks are revered as sacred animals. The herders mainly engaged in herding to produce yak milk products which provide them with their daily livelihood. This study investigates how different feeding practices impact milk productivity aiming to provide insights into efficient and sustainable yak farming. Yak herding is an age-old custom that has been carried down through the generations and is being carried out by herders throughout North Asia [1]. For transhumant pastoralists living in the frigid highlands between 2500 and 5000 meters above sea level, yak is their primary source of income [2]. Because of their unique nature and traits, Yak can only survive in the frigid mountains. In contrast to herding other domestic animals like sheep, cows, etc., this task is more difficult because the herders must relocate with them periodically in order to survive. While the other members of the family stay in their permanent communities, the herders must move with their herds every year between summer and winter in search of better rangeland and resources [3]. The yak is valued in the communities for its social and cultural significance in addition to its economic importance [4]. Feed Management plays a crucial role in yak herding, as it directly impacts the health, productivity, and overall well-being of the animals. Yaks primarily graze on natural pastures, but seasonal variations in forage availability can affect their nutrition [5]. During harsh winters, when grazing becomes difficult due to heavy snowfall, supplementary feeding is essential to prevent malnutrition and maintain body condition. Proper nutrition enhances milk production, supports growth, and improves the reproductive efficiency of yaks [6]. Additionally, well-fed yaks are more resilient to diseases and harsh climatic conditions, ensuring sustainable herding practices. Therefore, effective feeding strategies are vital for the long-term success of yak herding.

Estimating the economic efficiency of yak herders is crucial for understanding the sustainability and productivity of pastoral livelihoods, especially in high-altitude regions where yaks are a primary source of income and sustenance. By analyzing inputs such as labor, feed, and other cost variables against outputs like milk output, policymakers and researchers can identify opportunities to improve resource allocation and profitability. This information helps in designing targeted interventions, such as training programs or infrastructure investments, to enhance productivity while preserving traditional practices and ecological balance. Ultimately, evaluating economic efficiency supports the long-term viability of yak herding communities and their contribution to regional economies. Numerous studies have proposed that a range of socioeconomic and demographic factors influence farmers' efficiency [7]. The findings of a study on the profit efficiency of dairy farmers in South India reveal that farmers in the study area feed their cattle with green fodder and concentrate on increasing the milk yield of animals, thereby increasing profits. There is a need to enhance access to dairy production inputs and services (feed, veterinary, breeding, training, and credit services) for dairy farmers [8].

2. Objectives

- To assess the current feeding practices adopted by yak farmers.
- To analyze the effect of feeding practices in production through estimating the economic efficiency of the Yak herders.
- To identify challenges and constraints in feeding management.
- To suggest improved feeding strategies for enhanced productivity and sustainability.

3. Research Methodology

Yak herders are mostly located in the two westernmost districts of Arunachal Pradesh, Tawang and West Kameng[9]. Hence, these areas are the focus of the study. A planned schedule is used to interview Yak herders from one circle in West Kameng district and seven circles in Tawang district. The majority of the yak herders speak mostly their native Bro-keh language. Yamane's formula for estimating sample size was used to estimate 233 sample respondents, of whom 178 were herders from Tawang district and 55 were from the Dirang circle of West Kameng district. Primary data were collected through a structured interview schedule, which was administered personally to yak herders. Given that the majority of the respondents were illiterate or had low levels of formal education, the interview method was chosen over self-administered questionnaires to ensure accurate and comprehensive responses. The data collected from respondents were systematically entered and analyzed using Statistical Package for the Social Sciences, SPSS Version 26.0 (IBM Corp., Armonk, NY, USA) software and MS Excel. SPSS was utilized both for data entry and for conducting descriptive and inferential statistical analyses. Economic efficiency was estimated using FRONTIER Version 4.1 (Coelli, 1996).

The study employs Cobb Douglas Stochastic Cost Function to estimate economic efficiency. This study assumed that labour costs, veterinarian expenses, the grazing tax, the cost of concentrate feed, dry feed, and green fodder all affect the cost of producing milk. The general shape of the cost function employed in this investigation is as follows:

$$lnC = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + \beta_6 \ln X_6 + \exp(\text{Vi} - \text{Ui})$$

Where,

lnC = Cost of milk production
lnX_1 = Price of green fodder used in each farm
lnX_2 = Price of dry fodder used in each farm
lnX_3 = Price of concentrates and mineral mixtures used in each farm
lnX_4 = Cost of labour employed in each farm
lnX_5 = Cost of grazing tax paid by the herders
lnX_6 = Quantity of milk output produced in the farm
$\beta_1+\beta_2+\beta_3+\beta_4+\beta_5+\beta_6$ = are unknown parameters to be estimated
(vi - ui) = e = random error term

The Maximum Likelihood Estimation (MLE) cost function is used to estimate the parameters of a statistical model. The goal of MLE is to find the parameter values that maximize the likelihood function, which measures how well the model explains the observed data. For the estimation of economic efficiency stochastic frontier approach is used in this study. The stochastic frontier approach can segregate the error terms into two components, mainly inefficiency and random error[10]. Therefore for the estimation of economic efficiency, the stochastic cost frontier is used. Frontier 4.1 software is used for the estimation. At ($p < 0.05$) level of significance, the labour cost coefficient and the concentrate and mineral cost coefficient both show positive trends and are statistically significant. The study utilised statistical and econometric methods to analyse the data. Frequencies, percentages and descriptive statistics were also used to arrive at a conclusion based on the primary data using SPSS16 software.

4. Results and Discussion

4.1. Traditional Rangeland Management Practices

Traditional Rangeland Management Practices refer to indigenous or time-tested methods used by pastoralists and herders to sustainably manage grazing lands,

ensuring long-term productivity and ecological balance. These practices are often based on deep local knowledge of climate, soil, vegetation, and animal behavior. During the summer months, yak herders move their herds to higher elevations, where alpine meadows provide abundant grazing opportunities [11]. The higher altitudes offer cooler temperatures and richer vegetation for the yaks to feed on [12]. Yak herders follow traditional migration routes that have been passed down through generations. These routes are well-established and take into account factors such as topography, weather patterns, and the availability of water and forage [13]. Seasonal migration is not just a practical necessity for yak herders but also holds cultural significance. It is deeply rooted in the traditions, customs, and way of life of these communities, shaping their identity and social organization. Migration often involves entire families or communities, and it fosters a sense of solidarity and cooperation among members [14]. Seasonal migration of yak herders faces various challenges, including changes in land use patterns, encroachment on traditional grazing lands, infrastructure development, and conservation policies that restrict mobility. Additionally, climate change poses a significant threat, with rising temperatures, erratic weather patterns, and glacier melting affecting the availability of grazing resources and the timing of migration.

The community's approval of the village leader's choice to relocate is essential for controlling the pastures' seasonal use. The transhumant groups of the Monpa tribe, particularly the yak herders, have established a mobile village administration that functions regularly despite the group members' frequent relocations between mountain meadows. Following the *Mang* revision and simplification of the village administration's unwritten regulations in response to the challenging conditions, the two officials selected from the villages—known as the dropons—are granted total authority over the herding administration. The word "*dropon*," which originally meant "pasture leader," originated from the Tibetan language. "*Pon*" means leader, while "*dro*" means pasture or meadow. Each village has its own set of arrangements in the meantime. Jang, Rho, Mukto, and many other villages in Tawang District are home to both herding and agriculturalist communities. The chief, known as the *Tsorgan*, consults with the village dropon before making the ultimate decision in these types of settlements [15]. The dropon accepts the herding administration as well as role of chieftain in villages such as Mago, Thingbu, and Luguthang in the Tawang district where the majority of the population is pastoral and there are little or no agricultural activities. In larger settlements, three dropons are selected each year instead of the usual two. Pastoralism may seem like a fairly straightforward economic endeavour at first, but because of the hard work and the need to understand the climate, weather, and milking practices, among other things, it demands a great degree of skill and dedication. All of these abilities were developed and transmitted from one generation to the next as they took part in or engaged in an expanding variety of pastoral activities. The leader who cultivated these qualities is the one suggested and selected. The person, who may or may not be elderly, will do his best to fulfill his actual responsibilities. He needs to be proficient in the Bhoti script because all necessary ceremonies are written in that language [5]. He plays a key role in decision-making, grazing land distribution, dispute resolution, and other procedures. The village herders meet at a predetermined spot to decide how to divide up the grazing areas for the current year and to schedule a time to relocate to the proper areas. Grazing grounds are often given through rotation, however in certain locations, lotteries are also used. Once the grazing grounds are assigned, the herders prepare to move towards their assigned grazing regions. No one may move before the planned day of the meeting. According to the lunar calendar, the dates for moving up to the grazing pastures are chosen on auspicious days. Each grazing area is delineated to keep other Brokpa's yaks out, as was previously described. This is essentially done to stop overgrazing in order to avoid pasture deficits and conflicts.

4.2. Feeding Practices and Feed Cost in Yak Farming

Yak farming relies heavily on grassland resources at elevations ranging from 3,000 to 5,000 metres. Alpine grazing pastures are dominated by Carex, Juncus, Agrostis, Festuca, Kobresia, Poa, Rhododendron, Poten-

tilla, Primula, and Danthonia species [16]. The vegetation primarily consists of broadleaf species. Sedges gradually replace grass species at higher altitudes. The highest concentration of endemic plants (e., Berberis mucrifolia, Corydalis megacalyx, Delphinium himalayai, Heraclium lallii) is found in the eastern Himalayan region, alpine shrub medows and rangeland [17].

Herders typically utilise sound management methods in conjunction with rotational grazing [1]. Households with small herds typically group their animals. The grazing areas are owned by the local communities, and herders have an agreement with the village council to use the grazing land by paying grazing tax, either individually or collectively. Mostly, the grazing tax is in the form of some portion of their milk products such as cheese and butter, conveniently in accordance with the herd size owned by yak farmers.

Many different wild species share the grassland resources, but the most significant ones are the takin (Budorcus taxicolor), blue sheep (Pseudovis nayaur), sambar (Cervus unicolor), and musk deer (Moschus chrysogaster) [18]. A decrease in the number of their predators is thought to be the reason behind the recent increase in numbers of some of these animals, most notably the blue sheep. The high altitude grazing land is home to these herbivore animals along with yak.

The main obstacle to successful yak milk production is the scarcity of natural forage throughout the lengthy winter season (November-March). The most popular winter fodder is hay, straw from barley, buckwheat, and turnip, which is kept in small quantities to support grazing and act as a backup supply of fodder when the pastures are covered in snow. **Figure 1** shows dry fodder stored in the storage compartment build in a stone house owned by a yak herder in zemithang valley of tawang district to be used as winter feed. The majority of writers concur that improving the quality and availability of winter feed ought to be a top priority. The most promising species for this are oats, cocksfoot, tall fescue, white clover, and Lucerne. The availability of green fodder is seasonal. Only in May, when the rainy season officially begins, can growth begin in the winter pasture region. Once more, plant development stops at the end of October as temperatures and moisture become too low to sustain. Significant losses in live weight are caused by the slow deterioration in both the quality and quantity of feed during the winter. In some areas of Mago village in the Tawang district, where there are rather high animal concentrations near the winter encampment, the lack of food during the winter can get fairly bad.

Figure 1. Dry fodder stored in the storage compartment build in a stone house owned by a yak herder in zemithang valley of tawang district.

As described in **Table 1**, the average cost for self-cultivated Green fodder is Rs. 10.93/- whereas for self-cultivated dry fodder, it is Rs.3.97/-. Many of the herders purchase dry fodder from herders who are available nearby at an average cost of Rs. 4.59/- and purchase green fodder for an average price of Rs. 4.21/-. The average cost for locally available green fodder is Rs. 21.76/- and Rs. 14.27/- for dry fodder per herder. The cost of self-cultivated and locally available green and dry fodder an imputed cost which the herders do not incur in cash but their value is estimated as time and effort are invested in collecting and growing these fodders. The average cost for homemade concentrates per herder is Rs. 78.45/- and Rs. 48.04/- for purchased concentrates and mineral mix daily. The homemade mineral mix is prepared using various fodders such as Maize flour, Mustard oil, milk residue, vegetables and salt. The ingredients in the mixture would differ from place to place. The purchased concentrates are mostly palm oil cake, dried mustard cake and concentrated mineral mix which is available in the market for sale.

Table 1. Feed cost in Yak farming (in Indian rupees/ per day).

Fodder Type	Mode of Fodder Availability	Quantity (in kg)	Price (in Rs.)	Cost (in Rs.)	Average Cost (in Rs.)
Green Fodder	Self-cultivation	728	3.5	2548	10.93562
	Purchased	327	3	981	4.2103
	Locally available	2029	2.5	5072	21.76824
	Total	**3084**		**8601**	**36.91416**
Dry fodder	Self-cultivation	265	3.5	927	3.978541
	Purchased	357	3	1071	4.596567
	Locally available	1330	2.5	3325	14.27039
	Total	**1952**		**5323**	**22.84549**
Mix concentrates and minerals	Home-made	914	20	18280	78.45494
	Purchased	448	25	11194.5	48.04506
	Total	**1362**		**29474**	**126.4979**

Source: Data collected from field survey (2023–2024).

4.3. Estimation of Economic Efficiency

Table 2 illustrates the descriptive statistics of the variables used in the estimation of economic 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 with an average cost of labour of Rs. 667.59/-. The average cost incurred in green fodder, dry fodder and other concentrates and minerals is Rs. 36.91/-, Rs. 22.84/-, Rs. 126.49/- respectively. As shown in **Figure 2**, hydrogenated vegetable oil used in concentrated mix to feed Yak by yak herders. The average milch herd size is 16 in the sample. These results show that most Yak herders are well-experienced when it comes to yak-rearing. The total average feed cost incurred by yak herders is Rs. 186.26/-. Other costs included labour costs and grazing tax paid for grazing in the community lands. It has been witnessed that many of the semi-nomadic yak herders do not own their land but are paying tax to the community which originally claims the right to the lands where the herders graze. Mostly the grazing and other taxes such as road tax are paid in the form of milk products such as cheese and butter derived from yak milk. A herder incurs an average grazing tax of Rs. 39.25/- per day. These taxes are paid only for the summer grazing which takes place for around 3 to 4 months. The majority of the herders in the sample belong to the large herders category which accounts for 75.1% of the total sample herders. The herders live a tough life migrating seasonally with their herds for grazing purposes. So, they need to hold more than 7 milking animals to carry their dairy production. As per the study, 8.2% of the herders fall under the small herders who have less than 4 milch animals and only 16.7% of the herders are from the medium category holding 5 to 7 milch animals [19].

Table 2. 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
Cost of Milk Production (in rupees)	233	548	1772	893.11	207.62
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 rupees)	233	17	119	36.91	19.883
Dry Fodder (in rupees)	233	0	70	22.84	12.972
Concentrates and Minerals (in rupees)	233	20	325	126.49	53.080
Labour (in rupees)	233	450	1273	667.59	146.27
Grazing Tax (in rupees)	233	13	100	39.25	19.051

Note: Data collected from field survey (2023–2024).

Figure 2. Hydrogenated vegetable oil used in concentrated mix to feed Yak by a yak herder in khrimu village of kitpi circle in Tawang district.

4.4. Estimation of Stochastic Frontier Cost Function

The economic efficiency is estimated through maximum likelihood estimates of the Cobb-Douglas cost function [20]. MLE is a technique for estimating a statistical model's parameters. By giving the model's parameters values, the MLE approach produces a distribution that provides the observed data the highest probability—that is, parameter values that maximise the likelihood function [21]. The maximum likelihood estimate of the cost function of the milk production cost for the yak herders in Arunachal Pradesh is displayed in **Table 3**.

The only factors that significantly affect economic efficiency are labour expenses and the cost of concentrates and other minerals. The co-efficient value shows how sensitive the price of producing yak milk is to each of its independent variables. At the 0.05 level of significance, the labour cost coefficient and the concentrate and mineral cost coefficient both show positive trends and are statistically significant. As shown in **Figure 3**, Preparation of home-made concentrate and mineral mix for animal feed by a yak herder in mirba village of mukto circle in Tawang district. It suggests that there is a direct correlation between these variables and the cost of producing yak milk. The positive coefficient means that

the cost of producing milk will increase by 0.0287 per cent for every per cent increase in concentrate and mineral prices. In a similar vein, the positive labour cost co-efficient suggests that a per cent rise in labour costs will result in a 0.062 % increase in milk production costs. The co-efficient values of dry and green fodder show positive trends, suggesting a favourable correlation with the cost of producing milk. Nonetheless, there is a negative correlation between the amount of milk produced and the co-efficient of the grazing tax's value, suggesting a negative association with the cost of milk production. Generalized likelihood ratio (LR) statistic is used to test the null hypothesis for the absence of inefficiency effects in the Cobb-Douglas stochastic frontier cost function. The presence of economic inefficiency was tested by the Likelihood Ratio (LR) test. The null hypothesis (H_0) implies that the gamma (γ) value is zero. The alternative hypothesis (H_1) explains that 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. The LR value is 7.146 and the critical chi-square value ($\chi^2_{0.05}$) is equal to 11.91 (obtained from Kodde & Palm, 1986). The LR test value is less than the critical value, and it is statistically not significant, which implies that the null hypothesis is accepted. Hence it is right to state that there are no inefficiency effects in the cost function and the surveyed Yak Herders in the study area are cost-efficient.

Table 3. Maximum-Likelihood Estimates of the Cobb-Douglas Cost Function of the Yak Herders.

Production Function	Parameters	Co-Efficient	Standard-Error	t-Ratio
Constant	β_0	8.8676	1.1240	7.1488**
Green Fodder	β_1	0.0475	0.2447	0.1942
Dry Fodder	β_2	0.1623	0.1342	1.2098
Concentrates and other minerals	β_3	0.0287	0.0486	5.9011**
Labour Hours	β_4	0.0620	0.0903	6.8750**
Grazing Tax	β_5	−0.1181	0.2166	−0.5453
Milk Output	β_6	−0.2744	0.1855	−1.4798
Inefficiency Effects				
Sigma-squared		0.6801	0.0601	11.303
Gamma		0.09218	0.00178	0.00128
LR test off the one side error				7.146
Log-Likelihood function				−285.716

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

Figure 3. Preparation of home-made concentrate and mineral mix for animal feed by a yak herder in mirba village of mukto circle in Tawang district.

4.5. Economic Efficiency of Yak Herders

Yak herders' specific economic efficiency an important measurement tool in maximizing milk production at the individual herders' level. **Table 4** shows the frequency distribution of dairy Herders under different levels of economic efficiency of milk production. The minimum economic efficiency in the sample is 57.56 per cent whereas, the highest level of economic efficiency attained by the yak Herders is 91.36 per cent. The mean economic efficiency of the dairy farm producers is 82.52 per cent. There is room for potential improvement in the economic efficiency level by 17.48 per cent which can be achieved by proper utilisation of available input resources.

Around 73.8 per cent of the Herders operate with an economic efficiency that ranges between 81 to 90 per cent. 22.7 per cent of Herders operate with an economic efficiency that ranges between 71 to 80 per cent. Only 0.4 per cent of the entire sample size operates below 61 per cent of economic efficiency. Only 0.9 per cent of the sample size has achieved economic efficiency between 91 to 100 per cent. The mean efficiency of small Herders, medium Herders and large Herders is almost the same (80.66 per cent, 82.51 and 82.72 per cent, respectively). The medium (5 to 7 milch animal) and large Herders (more than 7 milch animal) are slightly more efficient than the small Herders (1 to 4 milch animal) when it comes to economic efficiency. Based on the economic efficiency, the average potential improvement for the economic efficiency of milk production among the different farm sizes is also determined. The average potential for improvement is greater for small Herders (19.34 per cent). The medium and large Herders need to increase their mean technical efficiency only by 17.49 per cent and 17.28 per cent respectively.

Table 4. Deciles range frequency Distribution of Economic Efficiency of the Yak Herders.

Efficiency Level (Percentage)	Frequency	Percentage
≤ 60	1	0.4
61–70	5	2.1
71–80	53	22.7
81–90	172	73.8
91–100	2	0.9
Total	233	100
Mean Efficiency		82.52
Minimum Efficiency		57.56
Maximum Efficiency		91.36
Standard Deviation (δ)		5.842

Note: Calculation based on primary data.

To determine the economic efficiency of the different circles from Tawang and West Kameng District, the mean economic efficiency indices of the milk production from different circles from the study area are obtained. The mean economic efficiency of Tawang, Kipti, Lumla, Zemithang, Mukto, Jang, Lhou, and Thingbu circles is 81.50, 77.65, 84.43, 76.08, 78.07, 83.28, 81.31, and 85.05 respectively, which falls under the Tawang district. The mean economic efficiency of Dirang circles is 82.72, which is the only circle under West kameng district where yak herders have been observed. Thingbu circle have attained the highest mean economic efficiency of 85.05 per cent compared to rest of the circles.

To determine the economic efficiency of the Tawang and West Kameng Districts, the mean of economic efficiency indices of the milk production from these two districts area is obtained. It is observed that the mean economic efficiency of the Tawang and West kameng districts is 82.46 and 82.72 per cent respectively. The mean efficiency score of Tawang district, 82.46 per cent, is slightly deviated from the overall mean economic efficiency of 82.72, whereas the mean economic efficiency of West kameng district is the same compared to the overall mean economic efficiency (82.72 per cent).

4.6. Constraints in Feeding Management

4.6.1. Scarcity of Fodder During Winter

During winter, natural pastures are buried under heavy snow, making it difficult for yaks to graze. In-

sufficient nutrition leads to weight loss, reduced milk production, and overall weakness in the animals. Prolonged malnutrition increases vulnerability to diseases and mortality rates, significantly impacting the health and productivity of yaks. Extreme cold, coupled with inadequate fodder, often results in starvation, leading to a higher mortality rate among yaks. Young calves and aged yaks are particularly at risk due to their lower resistance to harsh conditions [22]. Additionally, yak herders store fodder like dried grass, straw, and supplementary feed in summer, which supports the winter feed requirement. This, however, increases their economic burden and physical effort. The high cost and difficulty in transporting additional fodder from lower altitudes add to the financial strain on herders living in remote villages like mago and thingbu in Tawang district. It has been observed that poor nutrition directly impacts milk yield, affecting the production of yak-based dairy products such as butter, cheese, and churpi. A decline in dairy output reduces the income of herders, affecting their economic stability. Malnourished yaks become more susceptible to infections, respiratory diseases, and parasitic infestations. Veterinary services in remote areas are often inadequate, making it difficult to treat sick animals. The herders depend on their traditional ethnoveterinary practices and natural herbs for cure. One of the major concerns of the yak herders is the unavailability of fodder and lower productivity during winter.

4.6.2. High Altitude Constraints

Herders in high-altitude regions face several constraints that make yak rearing particularly challenging. The extreme climate, with heavy snowfall and sub-zero temperatures, severely limits natural grazing areas during winter [23]. The steep, rugged terrain makes transportation of supplementary fodder difficult and costly. Additionally, limited infrastructure and lack of access to veterinary services exacerbate health risks for yaks. The remote locations where yak herders operate also hinder access to markets, restricting opportunities for selling yak-based products. Seasonal migration, a traditional practice to find better grazing grounds, is becoming increasingly difficult due to environmental changes and land-use restrictions [14]. Moreover, the socio-economic dependency on yak herding is at risk due to declining younger generations taking up alternative livelihoods, further threatening the sustainability of traditional herding practices. Yak rearing involves seasonal movement, which presents both mental and physical challenges for the young generations.

4.6.3. Lack of Access to Commercial Feed Limits Productivity

Lack of access to commercial feed limits productivity, reducing growth rates and milk production. The unavailability of high-quality supplementary feed forces herders to rely solely on natural pastures, which become scarce in winter [5]. Additionally, herders must store fodder like dried grass, straw, and supplementary feed in advance, which increases their economic burden. The high cost and difficulty in transporting additional fodder from lower altitudes add to the financial strain [24]. Due to their isolated regions, the yak herders have faced challenges in transport. A few years ago, it would take 2 to 3 days of journey by foot from mago village in tawang to reach nearby villages where a market is available. The load of dairy products such as cheese and butter are carried on horse for trading. The herders will fill up necessary fodders on their return journey. The lack of mobility forces yaks to survive on whatever limited fodder is available, exacerbating the problem. The Border Roads Organisation (BRO) plays a crucial role in developing and maintaining road infrastructure in high-altitude areas like Tawang in Arunachal Pradesh. The Border Roads Organisation has made significant contributions in high-altitude areas to facilitate yak herders primarily through the development and maintenance of road infrastructure. Vartak, also known as Project VARTAK is a project of the Border Roads Organisation under the Ministry of Defence of India. To improve connectivity in border areas, major roads such as the Guwahati-Tawang Axis and the Balipara-Charduar-Tawang Axis are vital networks. Vartak is also building a number of tunnels in areas of Western Arunachal Pradesh to expedite transit between remote locations and enable all-weather mobility in areas where fog is frequent. The Nechiphu Tunnel in West kameng district and the Sela Tunnel in tawang district are two notable tunnels. BRO constructs and maintains roads that improve accessibility to remote high-altitude areas where yak herders reside and graze

their livestock. These roads connect villages, grazing grounds, and traditional transhumance routes, making it easier for herders to transport yaks, fodder, and other supplies. Construction of three road projects Sangetstar-kharsangla (15.90 kms), Zimithang–Survasamba–LogBr–Khinzemane (11.70 kms) and Thingbu-Mago-Chuna (48 kms) of ITBP roads aggregating 75.60 Kms length has been entrusted to the Project.

4.6.4. Changes in Climatic Condition

Changing climatic conditions have significantly impacted the availability of natural fodder for yaks. Irregular snowfall patterns and increasing temperatures have altered pasture cycles, reducing the overall availability of grazing land. Drought-like conditions in some seasons and excessive snowfall in others make it difficult for herders to plan adequate feeding strategies[16]. The unpredictability of snowfall further exacerbates the problem, as sudden heavy snow can bury available forage, leaving yaks without sufficient nutrition. Limited access to veterinary services also impacts feeding management, as malnourished yaks are more susceptible to diseases. Without adequate intervention, these constraints threaten the sustainability of yak herding as a livelihood. Yak herders face multiple challenges in feeding management, particularly during winter months when natural forage is scarce[25]. The remote and rugged terrain makes transportation of supplementary feed difficult and expensive. Herders often rely on traditional grazing methods, which are becoming increasingly unsustainable due to changing climatic conditions and land-use restrictions. The unpredictability of snowfall further exacerbates the problem, as sudden heavy snow can bury available forage, leaving yaks without sufficient nutrition. Without adequate intervention, these constraints threaten the sustainability of yak herding as a livelihood.

5. Conclusion and Recommendations

The study underscores the need for optimizing feeding practices to improve the productivity and economic viability of yak farming. Implementing better feeding strategies, providing access to nutritionally balanced feed, and promoting scientific feeding methods can significantly enhance the efficiency of yak farming in Arunachal Pradesh. The results suggest that improving access to quality labor and nutritional supplements like concentrates could significantly enhance output efficiency. There remains scope for enhancing resource allocation strategies to reduce inefficiencies and improve economic sustainability in yak herding operations. In addition to utilising unconventional feed resources more effectively, the Complete Feed Block Technology is the most recent advancement in feed technology that makes livestock farming a profitable business by maximising the potential of locally accessible animal feed resources. The term "complete feed block"(CFB) refers to a small blend of processed materials, such as concentrates and roughages, intended to be used as the only source of compressed feed. ICAR-NRCY has successfully developed a feed block using CFB for yaks in their research centre situated in Dirang circle of West Kameng district which can be a perfect supplement for the yak herders as fodder during winter. Improving feed transportation infrastructure is crucial to ensuring the timely delivery of supplementary feed to remote yak-rearing areas. Strengthening veterinary support and nutritional guidance will also play a key role in maintaining the health and productivity of yaks. By implementing these strategies, the challenges faced by yak herders due to fodder shortages can be significantly reduced, contributing to sustainable livelihoods and the preservation of traditional herding practices. Further research and policy interventions are required to address feeding challenges and ensure sustainable yak farming practices.

Author Contributions

T.C. conceptualized the study, conducted fieldwork, and led the data collection process. M.M. performed the econometric analysis, including the stochastic frontier modeling and interpretation of results. O.M. contributed to the literature review, manuscript writing, and final editing. T.T. contributed to the interpretation of results and drafted the initial manuscript. M.K.M. reviewed the manuscript critically for intellectual content, contributed to editing, and finalized the submission. All authors read and approved the final manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors disclosed no conflict of interest.

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