Estimation of average daily gain in fat-tailed sheep at smallholder farms based on energy and protein intake

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Abstract. This study aimed to estimate average daily gain (ADG) of Fat-Tailed Sheep based on their energy and protein intake. Data were collected from 68 fat-tailed sheep raised at three smallholder farms in West Java, including feed intake and ADG records. The evaluation was conducted by comparing the intake of dry matter (DM), crude protein (CP), and total digestible nutrient (TDN) against the nutrient requirements estimated by the model, as well as by comparing observed and estimated ADG values. The results showed that DM, CP, and TDN intakes were below the estimated standard requirements. The comparison between observed and estimated ADG revealed high root mean square percentage error (RMSPE > 80%) and a low concordance correlation coefficient (CCC), indicating weak alignment between model outputs and field observation. These outcomes suggest that the current model does not yet provide reliable ADG predictions for fat-tailed sheep under field conditions, possibly due to limitations in observational data.

1 Introduction

Fat-Tailed Sheep (FTS) are an indigenous breed in Indonesia, widely recognized for their adaptability to tropical climates, ease of management, and distinctive fat tail which serves as an energy reserve [6]. The development of fat-tailed sheep farming in Indonesia is supported by a tropical climate suitable for local sheep farming and relies on adequate livestock nutrition, particularly energy and protein in feed [9]. Despite its potential, growth productivity remains low due to limited feed management. Evaluating nutrient adequacy is therefore essential, since the widely used nutrient requirement standards, such as NRC [13], were derived from studies in subtropical regions and may not be fully applicable under tropical conditions. Meanwhile, the nutrient needs of livestock in tropical areas tend to be higher than in subtropical areas [12].

As an alternative, a meta-analysis model was developed based on local experimental data to estimate energy, protein, and average daily gain (ADG) requirements for Fat-Tailed Sheep [1]. However, empirical validation of this model under smallholder farm conditions has rarely

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been performed. Therefore, this study was conducted to evaluate nutrient adequacy and validate the agreement between observed and estimated ADG, with the aim of providing more accurate feeding recommendations to improve the productivity of Fat-Tailed Sheep, particularly for smallholder farmers.

2 Materials and Methods

2.1 Sample Collection

The research was conducted from March to June 2025 at three farms: Kandangku Farm, Saudagar Farm, and Black Sheep Farm. Data were collected from 68 Fat-Tailed Sheep, with a subset of 13 animals selected for more detailed validation due to similarities in feed intake but differences in body weight and ADG. Although flock sizes exceeded 100 head at each farm, the study focused exclusively on Fat-Tailed Sheep, totaling 24 animals from Kandangku Farm with an average body weight 38.36 ± 6.47 kg, 8 from Black Sheep Farm with an average body weight 26.59 ± 3.33 kg, and 36 from Saudagar Farm with an average body weight 19.69 ± 3.37 kg. Feed samples are used according to the formulation of each farm to analyze their nutrient content.

2.2 Obtained Variables

2.2.1 Feed Intake

The feed intake of sheep can be measured using the following formula:

$$\text{DMI g kg}^{-1}\ \text{BW}^{0.75}\ \text{day}^{-1} = \frac{asfed\ intake\ (g) \times \%Dry\ Matter}{BW^{0.75}} \qquad (1)$$

$$\text{CPI g kg}^{-1}\ \text{BW}^{0.75}\ \text{day}^{-1} = \frac{DMI\ (g) \times \%Crude\ Protein}{BW^{0.75}} \qquad (2)$$

$$\text{TDNI g kg}^{-1}\ \text{BW}^{0.75}\ \text{day}^{-1} = \frac{DMI\ (g) \times \%TDN}{BW^{0.75}} \qquad (3)$$

Note:
DMI = Dry Matter Intake
CPI = Crude Protein Intake
TDNI = Total Digestible Nutrient Intake
$BW^{0.75}$ = Metabolic Body Weight

2.2.2 Observed Average Daily Gain (ADG)

The average daily gain (ADG) of sheep can be calculated using the following formula:

$$\text{ADG (g head}^{-1}\ \text{day}^{-1}) = \frac{FInal\ body\ weight\ (g) - Initial\ body\ weight\ (g)}{Length\ of\ observation\ (days)} \qquad (4)$$

2.2.3 Estimated Average Daily Gain (ADG)

The estimated average daily gain (ADG) can be calculated by inputting feed nutrient intake data into the regression equation model [1] for Fat-Tailed Sheep as follows:

$$\text{ADG based on DMI (g kg}^{-1}\text{ BW}^{0.75}\text{ day}^{-1}) = \frac{DMI\ (g\ kg^{-1}\ BW^{0.75}\ day^{-1}) - 57.6}{2.20} \quad (5)$$

$$\text{ADG based on CPI (g kg}^{-1}\text{ BW}^{0.75}\text{ day}^{-1}) = \frac{CPI\ (g\ kg^{-1}\ BW^{0.75}\ day^{-1}) - 6.33}{0.336} \quad (6)$$

$$\text{ADG based on TDN (g kg}^{-1}\text{ BW}^{0.75}\text{ day}^{-1}) = \frac{TDNI\ (g\ kg^{-1}\ BW^{0.75}\ day^{-1}) - 27.5}{1.22} \quad (7)$$

Note:

DMI = Dry Matter Intake
CPI = Crude Protein Intake
TDNI = Total Digestible Nutrient Intake
$BW^{0.75}$ = Metabolic Body Weight

2.3 Data Analysis

Nutrient adequacy was assessed by comparing actual intake with the requirements predicted by the meta-analysis model [1]. Observed ADG was compared with estimated ADG calculated from regression models, and using several analytical approaches including descriptive measures, paired *t*-test, correlation and regression analyses, as well as concordance correlation coefficient (CCC) and root mean square percentage error (RMSPE).

3 Results and discussion

3.1 Nutrient Adequacy Assessment Based on Estimation Models

Forage and concentrate usage varied among the three farms. Kangdangku Farm provided approximately 70.5 g DM and 489.26 g DM of concentrate, while Black Sheep Farm provided the same forage amount but higher concentrate (630.072 g DM). The concentrate composition at Kandangku Farm consists of tofu pulp and commercial concentrate at a ratio of 3:1, while the concentrate at Black Sheep Farm contains approximately 20% tofu pulp. The difference in the balance of forage and concentrate in the ration represents differences in protein, energy, and other nutrient content [14]. At Saudagar Farm, forage was replaced by fiber mix (117.7 g DM/day), combined with 739.5 g DM of concentrate. Fiber mix is used as a substitute for forage because of its high crude fiber content and texture, which stimulates livestock to produce saliva as a rumen pH buffer to maintain normal conditions [7].

Table 1. Nutrient composition of the ration (%DM) from proximate analysis.

Farm Name	DM (%)	Ash (%)	CP (%)	EE (%)	CF (%)	NFE (%)	TDN (%)
Kandangku Farm	23.95	13.76	10.58	4.58	21.73	49.35	65.94[19b]
Saudagar Farm	51.87	11.14	13.30	2.17	21.81	51.58	64.35[19b]
Black Sheep Farm	21.63	12.26	16.14	4.47	12.55	54.58	69.96[19a]

Note: DM = dry matter; CP = crude protein; EE = ether extract; CF = crude fiber; NFE = nitrogen-free extract; TDN = total digestible nutrient.
[19a]TDN (CF<18%, CP<20%) = 2.97 + 1.17(%CP) + 1.75(%EE) – 0.295(%CF) + 0.81(%NFE)
[19b]TDN (CF>18%, CP<20%) = 70.6 + 0.259(%CP) + 1.01(%EE) – 0.76(%CF) + 0.091(%NFE).

Proximate analysis of feed nutrient composition in three farms are presented in Table 1. The use of fiber mix makes the dry matter value in Saudagar Farm feed higher than in other farms, as well as the high proportion of tofu pulp and concentrate ingredients that tend to be more moist at Kandangku Farm and Black Sheep Farm. Proximate analysis indicated that all rations supplied adequate crude protein (>10%) and TDN (>60%) following basic standards for fattening sheep [4]. However, when compared with values predicted by the meta-analysis model, which suggests CP of 12% and TDN of 46% for a 20-kg sheep with ADG 100 g/day [1]. Each farm in this study has a different feed formulation and consumption pattern, depending on the management strategy and type of raw materials used. The description of DM, CP, and TDN intakes is presented to provide an overview of the nutrient adequacy received by livestock in each farm.

Table 2. Average nutrient consumption of sheep in three farms.

Farm Name	Dry Matter Intake (g head^{-1} day^{-1})	Crude Protein Intake (g head^{-1} day^{-1})	Total Digestible Nutrient Intake (g head^{-1} day^{-1})
Kandangku Farm	474.450	50.197	312.862
Black Sheep Farm	237.930	38.401	166.454
Saudagar Farm	533.685	70.980	343.451

Daily nutrient intake (Table 2) also showed variation of feed intake. The low CP and TDN intakes at Black Sheep Farm indicate that the feed used has high CP and TDN values, so that in meeting their nutritional needs, the livestock consume less feed [10]. This shows that the high density of CP and TDN in the ration can cause the requirement to be met in smaller consumption amounts and accelerate satiety. This finding highlights that nutrient richness does not necessarily translate into higher consumption because ruminants regulate intake according to metabolic needs. Consumption differences may also be influenced by palatability, environmental conditions, physiological status, sex, and ration composition [2,5,11].

Table 3. Nutrient adequacy of sheep in three farms.

Parameter		Kandangku Farm	Black Sheep Farm	Saudagar Farm
Number of data (head)		24	8	36
Average ADG (g kg^{-1} BW$^{0.75}$ day^{-1})		11.889	14.613	14.355
Dry Matter (g kg^{-1} BW$^{0.75}$ day^{-1})	Consumption	31.435	20.651	56.965
	Estimation	83.757	89.749	89.181
	Balance	-52.321	-69.098	-32.216
Crude Protein (g kg^{-1} BW$^{0.75}$ day^{-1})	Consumption	3.326	3.33	7.576
	Estimation	10.325	11.240	11.153
	Balance	-6.999	-7.907	-3.577
Total Digestible Nutrient (g kg^{-1} BW$^{0.75}$ day^{-1})	Consumption	20.729	14.447	36.659
	Estimation	42.005	45.328	45.013
	Balance	-21.276	-30.881	-8.354

Note: BW$^{0.75}$ = metabolic body weight.

Nutrient adequacy evaluation was conducted to determine the extent to which the actual intake (DM, CP, and TDN) in Fat-Tailed Sheep in three farms met the estimated requirements based on a meta-analysis model [1]. The difference between actual intake and estimates showed nutrient adequacy deviations that could affect livestock growth performance. Nutrient adequacy calculations (Table 3) showed that actual DM, CP, and TDN intakes were consistently lower than predicted requirements. This deficit may result from insufficient DM intake, imbalanced ration formulation, limited palatability, feeding systems, or stocking density, all of which influence actual feed intake. The quality and balance of nutrients in the ration greatly influence growth efficiency in ruminants. High-energy feed can support growth, but an imbalance with protein can limit daily weight gain efficiency. Therefore, ruminant ration formulation needs to consider the balance of protein and energy availability in the right amounts and at the right times (synchronization) [3].

3.2 Suitability of the Daily Weight Gain Estimation Model

Descriptive statistics (Table 4) were used to provide an overview of nutrient intake (DM, CP, TDN) and observed and estimated ADG based on nutrient intake in two data groups (n=68 and n=13).

Table. 4 Descriptive statistics database consumption and ADG.

Parameter	Unit	n	Mean	SD	Min.	Max.
Initial Body Weight	kg	68	27.091	9.857	16.600	56.200
		13	22.014	5.806	14.675	38.358
DM Intake	g day^{-1}	68	477.983	134.362	237.930	829.920
		13	572.700	174.040	237.930	829.920
CP Intake	g day^{-1}	68	59.812	17.970	38.402	110.379
		13	75.696	23.048	38.402	110.379
TDN Intake	g day^{-1}	68	311.831	83.642	166.454	534.092
		13	370.164	109.559	166.454	534.092
ADG Observation	g day^{-1}	68	153.447	50.621	72.973	272.973
		13	137.568	24.858	104.545	181.818
ADG Estimated based on DMI	g day^{-1}	68	191.083	61.074	81.968	351.055
		13	234.137	79.109	81.968	351.055
ADG Estimated based on CPI	g day^{-1}	68	159.173	53.483	95.452	309.671
		13	206.447	68.595	95.452	309.671
ADG Estimated based on TDNI	g day^{-1}	68	229.478	74.605	-9.577	415.239
		13	280.872	89.803	113.897	415.239

Note: n = number of data; SD = standard deviation; DM = dry matter; CP = crude protein; TDN = total digestible nutrient; ADG = average daily gain.

Table 5. Pearson correlation between estimated ADG and observed ADG.

Pearson Correlation Test			**Estimated ADG based on**		
			DMI	**CPI**	**TDNI**
Observed ADG	n=68	r	0.116	0.166	0.117
		P-value	0.347	0.176	0.342
	n=13	r	-0.175	-0.147	-0.178
		P-value	0.567	0.633	0.558

Note: n= number of data; r= Pearson correlation value; DMI= dry matter intake; CPI= crude protein intake; TDNI= total digestible nutrient intake
*Significant correlation (P<0.05).

Validation was performed to examine the relationship between estimated and observed ADG. Pearson correlation analysis (Table 5) was used to assess the direction and strength of the linear relationship between each estimated and observed ADG. The Pearson correlation values indicate a very weak positive relationship for each variable in model 1 (n=68). Meanwhile, for model 2 (n=13), all Pearson correlation values indicate a weak negative relationship. Neither model shows a significant relationship between observed ADG and estimated ADG for all parameters tested (P>0.05). Overall, no model shows a strong or significant linear relationship between observed ADG and estimated ADG.

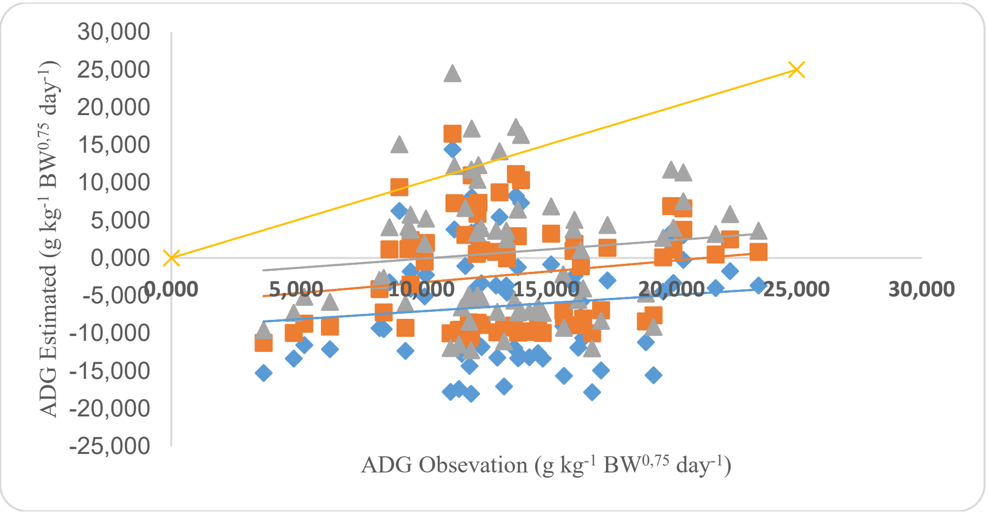

Fig 1. Relationship between observed ADG and estimated ADG based on DMI (- ◊ -), CPI (- □ -), and TDNI (- Δ-) in model 1.
ADG Observed - Estimate DMI : y = 0.2445x – 2.547 (R^2= 0.0137).
ADG Observed - Estimate CPI : y = 0.2875x – 6.1273 (R^2= 0.0275).
ADG Observed - Estimate TDNI: y = 0.2146x – 9.2272 (R^2= 0.0134).

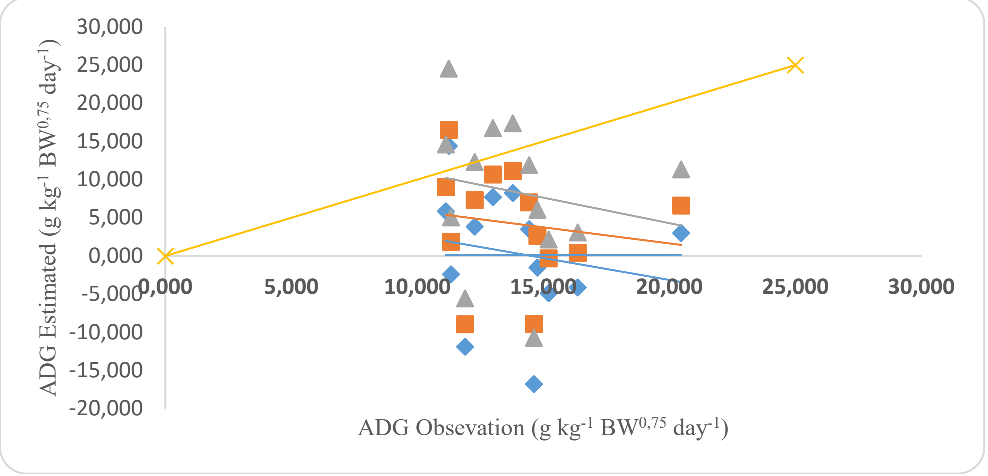

Fig. 2 Relationship between observed ADG and estimated ADG based on DMI (- ◊ -), CPI (- □ -), and TDNI (- Δ-) in model 2.
ADG Observed - Estimate DMI : y = -0.642x + 9,1152 (R^2= 0.0307).
ADG Observed - Estimate CPI : y = -0.4223x + 10,087 (R^2= 0.0215).

ADG Observed - Estimate TDNI : y = -0.6683x + 17,657 (R^2=00321).

Regression analyses (Figures 1 and 2) produced very low R^2 values (1.3–2.8% for model 1; 2.1–3.2% for model 2), indicating that observed ADG explained only a small fraction of the variation in estimated values, while the remainder is affected by variables not included in the model. In model 2, negative slopes (Figure 2) suggested an inverse trend, meaning that higher observed ADG corresponded to lower predicted ADG. This may stem from using group-level feed intake data alongside individual growth measurements, which introduces variability due to differences in intake within group pens. This difference in observation units has the potential to cause significant variation in the data, which can affect the direction and strength of the relationship in the regression model.

Table 6. Paired *t*-test, CCC, and RMSPE results between estimated and observed ADG.

Sample Test	n	R^2	*T*-test	CCC	RMSPE (%)
ADG Estimate DMI – ADG Observation	68	0.013	0.000*	0.016	177.95
	13	0.031	0.000*	-0.030	114.45
ADG Estimate CPI – ADG Observation	68	0.028	0.000*	0.031	143.91
	13	0.021	0.000*	-0.037	88.76
ADG Estimate TDNI – ADG Observation	68	0.014	0.001*	0.033	126.16
	13	0.032	0.083	-0.070	83.58

Note: n = number of data; R^2 = determination coefficient; *t*-test = significance of *t*-test result; CCC = concordance correlation coefficient; RMSPE = root mean square percentage error; DMI = dry matter intake; CPI = crude protein intake; TDNI = total digestible nutrient intake
*Significant ($P<0.05$).

A paired *t*-test was conducted to evaluate whether the mean estimated ADG differed significantly from the mean observed ADG. As shown in Table 6, all P-values in model 1 ($P<0.05$), indicating a significant difference between the estimated and observed ADG. A similar outcome was observed in model 2, where most estimates differed significantly from the observed ADG. The exception was the TDNI-based estimate, which had a P-value of 0.083. Since this value exceeds the 5% significance threshold, the TDNI-based prediction in model 2 can be regarded as the estimate most closely aligned with the actual ADG.

The CCC value in the estimated ADG with the observed ADG in model 1 has a positive range, but the value is very low, indicating that the suitability is relatively weak. Meanwhile, in model 2, the CCC value is in the negative range, indicating that there is a mismatch between the estimated value and the observed value. Model 1 shows better conformity than model 2, although neither model shows strong predictive ability.

Estimates based on TDNI showed the best prediction performance with the highest accuracy among the three estimates tested in models 1 and 2. This can be seen from the lowest RMSPE value among the other estimates. However, this value is still relatively high. An RMSPE value >10% is considered inaccurate in describing the actual conditions [8]. Nevertheless, the TDNI-based prediction in model 2 appears to be the most consistent, given that it yields the smallest RMSPE value and does not differ significantly from the observed ADG based on the *t*-test results.

The discrepancy between the estimated and observed ADG value can be caused by several factors. The main cause is the colony maintenance system, which uses collective feed intake measurements rather than individual ones. Although model 2 uses data with uniform feed intake, the estimation results still show significant deviation, indicating that factors other than feed intake contribute to ADG variation. Another factor contributing to differences in estimated values is differences in type and quality feed between farms. In terms of livestock, it is possible that the livestock used in the estimation model differs from the livestock observed, as it is currently difficult to obtain purebred sheep. In addition, sheep may experience physiological disorders that cause reduced growth. This occurs because the process of nutrient absorption varies among sheep.

4 Conclusion

The evaluation showed that the nutrient intakes (DM, CP, and TDN) of Fat-Tailed Sheep at smallholder farms were consistently below estimated requirements. Validation showed weak correlations, limited explanatory power (low R^2), low CCC scores, and high RMSPE, demonstrating poor agreement between estimates and field observations. The meta-analysis-based model requires further refinement before being applied as a predictive tool under field conditions.

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