Evaluation of dietary energy and protein adequacy for Priangan sheep

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Abstract. This study aimed to evaluate the dietary energy and protein adequacy for Priangan sheep. The evaluation was carried out by comparing the estimated average daily gain (ADG) calculated from dry matter intake (DMI), crude protein intake (CPI), and total digestible nutrient intake (TDNI) with actual observed ADG data from several smallholder farms. A total of 124 Priangan sheep were recorded from four smallholder farms located in Bogor and Bandung, West Java. The data were analyzed using linear regression, Pearson correlation analysis, paired t−test, concordance correlation coefficient (CCC), and root mean square percentage error (RMSPE). The results showed that the intake of DM, CP, and TDN on several farms was still below the estimated requirements. The validation results indicated that the ADG estimation based on crude protein intake explained 25.8% of the total variation, had a moderate correlation (0.508), better agreement (0.346), and a lower RMSPE (78.4%) compared to the dry matter and TDN estimations. However, all equations still showed low CCC values, indicating that the level of agreement between estimated and observed ADG remains inadequate and require further refinement.

1 Introduction

Priangan Sheep are known as one of the superior local sheep breeds with good meat production potential and are widely raised in smallholder farms. However, their productivity in smallholder settings often does not reach its maximum potential. One of the contributing factors is the provision of feed that does not fully meet nutritional requirements, especially essential nutrients that support growth and production [1]. To date, the most widely used reference for determining the nutritional requirements of small ruminants is the Nutrient Requirements of Sheep [2], which was developed based on standards in subtropical countries. However, tropical climatic conditions in Indonesia demand different energy requirements [3]. This causes NRC-based standards to be less appropriate for Indonesian farming conditions, thus a more contextual standard is needed to support the productivity of local livestock. One relevant reference for the nutritional requirements of local sheep in Indonesia is the meta-analytic study by Jayanegara [4], which developed standards for dry matter, protein, and energy requirements based on the desired average daily gain (ADG) for Priangan

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sheep, Fat-Tailed sheep, and local sheep. However, this reference has not yet been validated due to the lack of direct evidence in field conditions. Therefore, this study was conducted to evaluate nutrient adequacy and to validate the standards for energy and protein requirements of Priangan sheep directly under smallholder farm conditions.

Evaluation of nutrient adequacy and validation of these standards was carried out by measuring feed provision, intake, and average daily gain (ADG). The data obtained were then used to estimate ADG based on protein and energy intake using equations presented in the meta-analytic study [4] and nutrient intake was evaluated against the standards from that study. The results are expected to validate whether the equations are consistent with observational data so that the standards proposed by Jayanegara et al. can be used as a reference for the energy and protein requirements of Priangan sheep under Indonesian environmental conditions.

2 Materials and methods

2.1 Data collection

The data used in this study were secondary data consisting of daily feed intake and average daily gain (ADG) records of Priangan sheep raised on three different farms: Young Farmer Farm (60 heads) with an average body weight of 21.04 ± 2.44 kg, ABA Farm (26 heads) with an average body weight of 17.45 ± 5.81 kg, Agro Makmur (29 heads) with an average body weight of 18.56 ± 1.53 kg, and Saudagar Farm (9 heads) with an average body weight of 21.54 ± 3.58 kg. Thus, the total observed population in model 1 was 124 heads. Subsequently, a subpopulation of 22 data points was selected for model 2, consisting of sheep with similar average feed intake but different body weights and ADG. This subpopulation was used to minimize intake variation and clarify the relationship between nutrient intake and body weight gain, as well as to assess the validity of estimation at the group level.

2.2 Obtained variables

2.2.1 Average Daily Gain (ADG):

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

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

2.2.2 Feed Intake

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

$$\text{DMI (g/kg MBW/d)} = \frac{\text{asfed intake (g)} \times \%\text{DM}}{\text{MBW}} \quad (2)$$

$$\text{CPI (g/kg MBW/d)} = \frac{\text{DMI} \times \%\text{CP}}{MBW} \quad (3)$$

$$\text{TDNI (g/kg MBW/d)} = \frac{\text{DMI (g)} \times \%\text{TDN}}{\text{MBW}} \quad (4)$$

Note :
DMI = Dry Matter Intake
CPI = Crude Protein Intake
TDN = Total Digestible Nutrient
MBW = Metabolic Body Weight

2.2.3 Estimated Average Daily Gain

The estimated average daily gain (ADG) of sheep can be calculated using the estimation formulas from Jayanegara et al. ADG estimation according to Jayanegara et al.:

$$\text{ADG based on DMI} = \frac{\text{DMI (g/kg MBW/d)} - 57.6}{2.20} \tag{5}$$

$$\text{ADG based on CPI} = \frac{\text{CPI(g/kg MBW/d)} - 6.47}{0.295} \tag{6}$$

$$\text{ADG based on TDNI} = \frac{\text{TDNI (g/kg MBW/d)} - 28.2}{0.860} \tag{7}$$

Note :
ADG = Average Daily Gain
DMI = Dry Matter Intake
CPI = Crude Protein Intake
TDNI = Total Digestible Nutrient Intake
MBW = Metabolic Body Weight

2.3 Data analysis

Observed and estimated ADG values were evaluated for validity using several statistical analyses, including linear regression, Pearson correlation analysis, paired t-test, Concordance Correlation Coefficient (CCC), and Root Mean Square Percentage Error (RMSPE). Linear regression was used to quantify the proportion of variation in observed ADG explained by the estimated values. Pearson correlation analysis measured the strength of the linear relationship between observed and estimated ADG. The paired t-test was applied to determine whether the mean difference between observed and estimated ADG was statistically significant. The CCC was used to evaluate the level of agreement between observed and estimated ADG by combining measures of precision and accuracy. RMSPE was calculated to quantify the magnitude of prediction error between estimated and observed ADG values.

3 Results and discussion

3.1 Nutrient adequacy evaluation

Feeding practices varied among the farms included in this study. Table 1 summarizes the nutrient composition of the diets applied at each farm. Young Farmer Farm, two experimental rations were formulated, namely Ration A, consisting of 33.14% concentrate and 66.86% corn straw silage, and Ration B, consisting of 32.94% concentrate and 67.06% corn stover silage. ABA Farm comprised 63% concentrate and 37% silage. Agro Makmur Farm, the ration was formulated from a combination of tofu by-product, concentrate, and silage. Saudagar Farm implemented a diet consisting of 70% concentrate, 20% structural fiber in the form of rice straw, and 10% cassava pulp.

Feed intake is one of the most important factors in evaluating livestock performance during rearing. Dry matter intake is directly related to the intake of nutrients, meaning that higher dry matter intake will increase nutrient supply for both maintenance and production. Table 2 shows nutrient adequacy for achieving 100 g/day ADG. The difference between actual and estimated intake in Table 2 indicates the deviation in nutrient adequacy.

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

Farm Name	DM (%)	Ash (%)	CP (%)	CF (%)	EE (%)	NFE (%)	TDN (%)
YFF - A	44.04	9.22	11.38	27.80	4.39	47.21	53.77
YFF – B	40.88	7.96	12.53	24.85	4.41	50.25	58.50
ABA Farm	51.51	11.88	18.33	13.57	3.76	52.46	69.27[a]
Agro Makmur	35.65	8.79	7.56	9.57	3.45	70.63	75.19[b]
Saudagar Farm	51.87	11.14	13.3	21.81	2.17	51.58	64.35[b]

Note: DM = dry matter; CP = crude protein; EE = ether extract; CF = crude fiber; NFE = nitrogen-free extract; TDN = total digestible nutrient.
[14a]TDN (CF<18%, CP<20%) = 2.97 + 1.17(%CP) + 1.75(%EE) – 0.295(%CF) + 0.81(%NFE)
[14b]TDN (CF>18%, CP<20%) = 70.6 + 0.259(%CP) + 1.01(%EE) – 0.76(%CF) + 0.091(%NFE)

Feed intake of sheep at Young Farmer Farm met the nutrient requirements for Priangan sheep to achieve 100 g/d ADG. At ABA Farm, dry matter intake was still insufficient, possibly due to the high protein and energy content of the feed, which caused the sheep to feel that their daily nutrient needs were already satisfied and thus reduced their intake. At Agro Makmur, nutrient intake was still below the standard due to both lower nutrient content and inadequate feed provision. At Saudagar Farm, dry matter and crude protein intake were not met, most likely because energy intake was already sufficient, leading the animals to stop eating. Overall, several farms did not yet meet the nutrient requirements necessary to achieve optimal growth performance in Priangan sheep.

Table 2. Nutrient adequacy of sheep in each farm

Parameter	Young Farmer Farm	ABA Farm	Agro Makmur	Saudagar Farm
Number of data (heads)	60	26	29	9
MBW	9.823	8.539	8.941	9.998
Average ADG (g/kg MBW/d)	12.165	16.082	13.339	10.020
Dry Matter (g/kg MBW/d)				
Intake	84.943	70.106	40.033	55.341
Estimated	77.878	89.589	85.561	76.515
Balance	+7.065	-19.483	-45.528	-21.174
Crude Protein (g/kg MBW/d)				
Intake	10.236	12.850	3.026	7.360
Estimated	9.264	10.657	10.178	9.102
Balance	+0.972	+2.193	-7.152	-1.742
Total Digestible Nutrient (g/kg MBW/d)				
Intake	53.474	48.556	30.101	35.612
Estimated	35.936	41.340	39.481	35.307
Balance	+17.539	+7.216	-9.380	+0.305

3.2 Description of observed and estimated data

The database used for validating the estimation equations was obtained from secondary data consisting of individual sheep ADG records and feed intake data collected at the group level in colony pens. The mean observed ADG results show that models 1 and 2 did not differ greatly and had higher values compared to the mean ADG used in the meta-analysis [4] The average ADG of Priangan sheep ranged between 120–125 g/d (Table 3), which is higher than the average ADG of local sheep which ranged from 108.69–114.28 g/d [5].

Table 3. Description of ADG (average daily gain) and feed intake from observation and estimation

Parameter (g/head/ day)	N	Minimum	Maximum	Mean	SD
Dry Matter Intake	124	356.500	845.598	646.609	201.625
	22	356.500	845.598	618.249	145.176
Crude Protein Intake	124	26.951	154.998	82.269	33.382
	22	26.951	154.998	100.721	31.137
TDN Intake	124	233.648	585.661	425.440	111.937
	22	233.648	585.661	418.761	95.680
Observed ADG	124	32.759	208.333	120.019	38.398
	22	41.667	208.333	125.687	37.949
Estimated ADG (DMI)	124	−103.915	176.162	49.318	82.087
	22	−77.329	128.001	33.459	56.485
Estimated ADG (CPI)	124	−131.433	287.601	74.425	108.788
	22	−112.407	295.975	135.938	106.187
Estimated ADG (TDN)	124	−21.406	342.140	188.606	115.803
	22	19.843	332.997	178.463	101.378

Note: SD = standard deviation; N = number of data points; TDN = Total Digestible Nutrient; DMI = Dry Matter Intake; CPI = Crude Protein Intake.

Dry matter intake values in this dataset were consistent with the recommendations of Kearl, which state that sheep with body weights between 20–30 kg require 650–870 g/d of dry matter [6]. The high standard deviation in the data was due to differences in management and feeding practices across the farms. The observed DMI, CPI, and TDN values were then used to calculate estimated ADG using the Priangan sheep equations [4].

Estimated ADG values were negative except for TDN estimation in model 2. This was because the minimum intake of DMI, CPI, and TDN, according to the equations, was not sufficient to support weight gain in Priangan sheep. A positive ADG value from TDN estimation indicates that the level of TDN intake could increase Priangan sheep growth. According to Jayanegara et al., Priangan sheep weighing 20 kg require a minimum of 61 g/d crude protein intake with 267 g/d TDN.

3.3 Validation model

The estimated ADG results were compared with the observed ADG to validate the accuracy of the equations. Figures 1 and 2 below present the linear regression results of observed ADG against estimated ADG in both models.

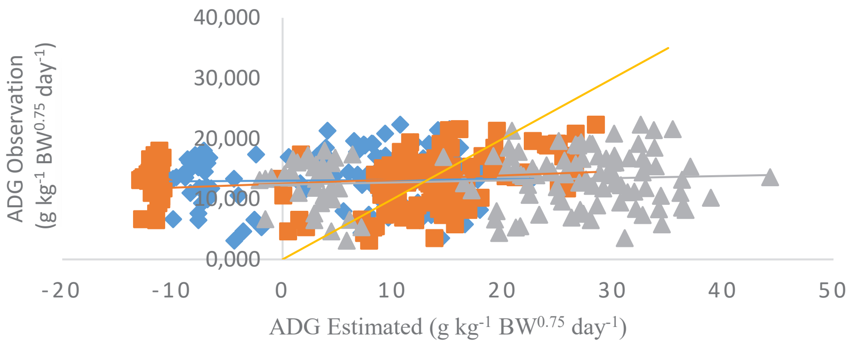

Fig. 1. Relationship between observed ADG and estimated ADG based on DMI (-◊-), CPI (-□-), and TDN (-Δ-) (N = 124)

ADG – Estimated DMI: $y = 0.0125x + 13.039$ ($R^2 = 0.0007$)

ADG – Estimated CPI: $y = 0.0678x + 12.549$ ($R^2 = 0.0373$)

ADG – Estimated TDN: $y = 0.036x + 12.373$ ($R^2 = 0.0106$)

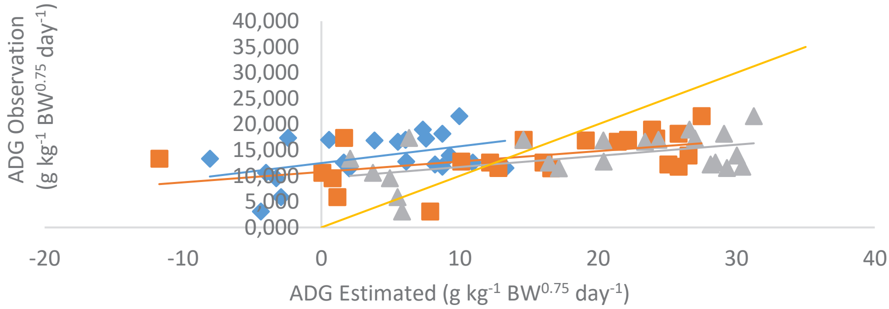

Fig. 2. Relationship between observed ADG and estimated ADG based on DMI (-◊-), CPI (-□-), and TDN (-Δ-) (N = 22)

ADG – Estimated DMI: $y = 0.3245x + 12.484$ ($R^2 = 0.197$)

ADG – Estimated CPI: $y = 0.202x + 10.763$ ($R^2 = 0.2579$)

ADG – Estimated TDN: $y = 0.2163x + 9.5525$ ($R^2 = 0.2628$)

The R^2 values of the three estimations in model 1 were lower than those in model 2. This indicates that bias existed in the observed ADG, which could not be explained by the estimated ADG results. Based on R^2, only 0.07–3.73% of the variation in the observed data could be explained by the estimation equations used. From Figure 2, it can be seen that the three estimation equations in model 2 could only explain 19.07–26.02% of the variation. Although the R^2 values were low, indicating weak relationships, all estimations in both models still showed positive associations, as indicated by the regression equations with positive slopes. This means that an increase in observed ADG was accompanied by an increase in estimated ADG. The unexplained variation between observed and estimated ADG was due to differences in observed ADG at similar intake levels and variations in feed efficiency among individual sheep.

Table 4. Results of paired t-test, correlation, CCC, and RMSPE of observed and estimated ADG

Test	N	Estimated ADG (Average Daily Gain)		
		DMI	**CPI**	**TDN**
P-value	124	≤ 0.05*	≤ 0.05*	≤ 0.05*
	22	≤ 0.05*	0.634	≤ 0.05*
Correlation (r)	124	0.026	0.193	0.103
	22	0.444	0.508	0.512
CCC	124	0.150	0.346	0.319
	22	0.012	0.106	0.048
RMSPE (%)	124	104.29	109.10	160.60
	22	98.37	78.41	80.34

Notes: N = number of data; DMI = Dry Matter Intake; CPI = Crude Protein Intake; TDN = Total Digestible Nutrient;
Correlation coefficient interpretation: 0.00–0.199 = very low; 0.20–0.399 = low; 0.40–0.599 = moderate; 0.60–0.799 = strong; 0.80–1.00 = very strong
*p-value ≤ 0.05 = significant.

The paired t-test results showed that estimated ADG in model 1 had significant values ($p < 0.05$), meaning that the averages of observed and estimated results were significantly different. In model 2, estimated ADG based on CPI showed non-significant results ($p > 0.05$), indicating no significant difference between the mean estimated ADG and observed ADG. Thus, CPI-based ADG estimation in model 2 demonstrated better validity because there was no mean bias.

The correlation values between observed and estimated ADG in model 2 ranged from 0.444–0.512, which can be interpreted as moderate relationships. In model 1, the correlations ranged from 0.026–0.193, which are classified as very low [7]. The strength of association in model 2 was better than in model 1, although neither model demonstrated a strong correlation with observed ADG.

The CCC values indicated discrepancies in all three estimation equations across both models, as they were far from 1. The CPI estimation showed the best CCC results, followed by TDN in model 2 (0.346 and 0.319, respectively). This suggests some accuracy in estimation but still poor agreement. RMSPE values showed the extent of deviation between predicted and observed values [8]. A higher RMSPE indicates greater deviation. In Table 3, CPI-based ADG estimation had the lowest RMSPE (78.41%) compared to others, suggesting that the CPI equation had the least deviation from observation. The high RMSPE values corresponded with the low R^2 values in the regression analysis, and vice versa [9]. This demonstrates that higher data deviation in RMSPE reduces the strength of the relationship between observed and estimated results.

The incomplete validation of the estimation equation under farm conditions is expected, as biological efficiency and nutrient utilization vary among individual animals. In contrast, the estimation of average daily gain (ADG) does not explicitly account for individual variation in maintenance energy requirements, metabolizable energy utilization, or protein efficiency, as defined in NRC-based feeding systems, resulting in discrepancies between predicted and observed performance [10]. Variability in feed efficiency among individuals may therefore lead to different ADG values despite similar dry matter intake. Moreover, differences in diet quality, feeding management, and feeding frequency influence rumen fermentation dynamics and metabolite availability, thereby affecting energy partitioning and nutrient use efficiency [11]. Additional variation arises from differences in feed type, nutrient density, and palatability among farms, which can enhance growth performance when diets of higher quality are provided [12]. Animal health status, environmental stressors, and housing conditions further contribute to deviations in growth responses [13]. Consequently, the estimation equation proposed by Jayanegara [4] cannot yet be applied as a sole reference for determining the metabolizable energy and crude protein requirements of Priangan sheep, and further refinement of the equation is required to align predictions with actual production conditions.

4 Conclusions

Nutrient intake in most farms did not meet the estimated requirements, except in Young Farmer Farm. The validation test showed that the CPI-based ADG estimation equation produced the most promising results, as it did not show significant mean bias and demonstrated the best accuracy compared to the other estimations. However, all estimation equations showed poor agreement in the CCC test when compared to the observed Priangan sheep ADG data. This indicates that the equations by Jayanegara et al. for estimating Priangan sheep ADG have not been fully validated and require adjustments before being applied as a standard for determining energy and protein requirements in Priangan sheep.

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