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Determination of Energy and Protein Requirements of Sheep in Indonesia using a Meta-analytical Approach

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ABSTRACT

The objective of this study was to determine energy and protein requirements, for both maintenance and gain, of sheep in Indonesia by using a meta-analysis method. A database was developed from various *in vivo* experiments involving sheep as the experimental animals in which energy intake, protein intake and average daily weight gain (ADG) were reported. A total of 38 articles consisting of 137 data points were integrated into the database. Different breeds (Priangan, fat-tailed and local) and sexes (male and female) were specified in the database. Maintenance and gain requirements of dry matter, energy and protein were determined by regressing ADG with dry matter intake (DMI), total digestible nutrient intake (TDNI) and crude protein intake (CPI), respectively. An intercept (where ADG= 0 g/kg MBW/d) and a slope (required nutrient intake per unit ADG) were taken as maintenance and gain requirements, respectively. Results revealed that all sheep breeds had similar energy requirement for maintenance (TDN_m). Energy requirement for gain (TDN_g) of Priangan breed was lower than other breeds; the breed required 0.860 g TDN for 1 g ADG. Fat-tailed and local breeds required 1.22 and 2.75 g TDN for 1 g ADG, respectively. All breeds also revealed relatively similar protein requirement for maintenance (CP_m), i.e. 6.27-6.47 g/kg MBW/d. Priangan breed required less CP for 1 g ADG (CP_g), i.e. 0.295 g. Requirements of CP_g for fat-tailed and local breeds were 0.336 and 0.497 g/g ADG, respectively. It was concluded that each sheep breed in Indonesia had specific TDN and CP requirements for gain, but similar requirements for maintenance.

Keywords: nutrient requirement, energy, protein, sheep, meta-analysis

ABSTRAK

Penelitian ini bertujuan untuk menentukan kebutuhan energi dan protein domba di Indonesia menggunakan metode meta-analisis. Berbagai eksperimen pakan/nutrisi yang menggunakan domba dan melaporkan peubah konsumsi energi, konsumsi protein dan pertambahan bobot badan (PBB) ditabulasi dalam suatu database. Sebanyak 38 artikel yang terdiri atas 137 data diintegrasikan pada database tersebut. Bangsa domba yang berbeda (Priangan, ekor gemuk dan lokal) dan jenis kelamin (jantan dan betina) juga diinformasikan. Kebutuhan hidup pokok dan pertumbuhan untuk bahan kering (BK), energi (TDN) dan protein (PK) didapatkan melalui regresi antara PBB dengan konsumsi BK, konsumsi TDN dan konsumsi PK. Kebutuhan hidup pokok didapatkan melalui nilai intersep regresi (ketika PBB= 0 g/kg bobot badan metabolik [BBM]/hari) sedangkan kebutuhan pertumbuhan adalah nilai kemiringan (konsumsi per unit PBB) dari persamaan regresi. Hasil menunjukkan bahwa semua bangsa domba yang diamati memiliki kebutuhan energi untuk hidup pokok (TDN_m) yang sama. Kebutuhan energi untuk pertumbuhan (TDN_g) dari domba priangan lebih rendah dibandingkan dengan bangsa domba lainnya; domba priangan membutuhkan 0,860 g TDN untuk setiap 1 g PBB. Domba ekor gemuk dan domba lokal membutuhkan 1,22 dan 2,75 g TDN untuk setiap 1 g PBB. Semua bangsa domba tersebut memiliki kebutuhan protein untuk hidup pokok yang sama (CP_m), yakni sekitar 6,27-6,47 g/kg BBM/hari. Kebutuhan protein untuk pertumbuhan (CP_g) dari domba priangan, domba ekor gemuk dan domba lokal adalah 0,295, 0,336 dan 0,497 g/g PBB. Disimpulkan bahwa setiap bangsa domba di Indonesia memiliki kebutuhan energi dan protein untuk pertumbuhan yang spesifik, namun memiliki kebutuhan hidup pokok yang sama.

Kata kunci: kebutuhan nutrisi, energi, protein, domba, meta-analisis

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INTRODUCTION

Current practice of ration formulation for various livestock in Indonesia, either ruminants (beef cattle, dairy cattle, sheep and goat) or monogastrics (poultry and swine), follows feeding standards developed in other countries, particularly National Research Council (NRC) standard of the USA (Indarsih, 2009; Baihaqi & Herman, 2012; Lestari *et al.*, 2015). Although other feeding standards such as from UK (AFRC), France (INRA), Australia (CSIRO) and Dutch (VEM-DVE) are available, they are rarely used in the country. However, using standard from other country may not be suitable because of a number of considerable differences such as (1) feed ingredient and nutritional quality, (2) environmental condition, and (3) animal breed and genetics (Salah *et al.*, 2014). It is well accepted that different feed and environmental condition (tropics vs temperate), for instance, affect nutrient utilization and partition, animal growth, body composition and, hence, energy and protein requirements of animals. Further, regarding animal breed and genetics, *Bos indicus* breeds have 10% less net energy for maintenance requirement than *Bos taurus* breeds (NRC, 2000; Chizzotti *et al.*, 2008). Thus, it is apparent that developing our own feeding standard is essential for animals under local condition in Indonesia.

A feeding standard generally has two parts, i.e. (1) nutrient requirement of animals, specific per species and at different physiological stages and (2) chemical composition of feedstuffs. The feeding standard has to, in turn, contribute to optimal diet formulation and allows proper nutritional management in an efficient, technical and economical way. Methods for determining energy and protein requirements of animals are mostly based on (1) calorimetric method and (2) comparative slaughter method. The calorimetric method uses respiration chamber to measure gas exchange, heat production during fasting, and loss of energy through urine and methane at maintenance level of animal feeding (Dong *et al.*, 2015). The comparative slaughter method employs feeding trials in which animals are fed at two or more levels of intake, and one of them is at maintenance level. Metabolizable energy (ME) intake and retained energy (RE) as the change in body energy content of animals are measured through this procedure. The slope of linear regression between RE and ME intake indicates efficiency of ME utilization or ME for gain (Chizzotti *et al.*, 2007; Zhao *et al.*, 2016). Both methods require relatively sophisticated research facilities and financial resources to perform the experiments in which these are among the main obstacles in Indonesia. Further, it may take quite long time to generate data from different experiments so that the energy and protein requirements are accurate and reliable.

A more recent method of determining nutrient requirements of animals is meta-analysis study using data from feeding trials across various independent experiments (Chizzotti *et al.*, 2008; Salah *et al.*, 2014; Oliveira, 2015). Although meta-analysis studies have been conducted by Indonesian researchers (Palupi *et al.*, 2012; Jayanegara *et al.*, 2014), the method has not been applied to the determination of nutrient requirement of animals in Indonesia. This method seems suitable for us since significant amount of data have already been generated on feed or nutrient intake, nutrient digestibility and production performance of animals. To date, determination of nutrient requirement on sheep by using a meta-analytical approach worldwide is scarce (Salah *et al.*, 2014). The objective of this study was, therefore, to determine energy and protein requirements, for both maintenance and gain, of sheep in Indonesia by using a meta-analytical approach. Since this is the first study of such objective in Indonesia, determination of nutrient requirement of other livestock species are subjected to further sequential studies provided that the results obtained are proved to be accurate and reliable through further studies.

MATERIALS AND METHODS

Database Development

A database was constructed from published articles on feeding trials involving sheep as the experimental animals and in which the experiments were performed in Indonesia. The articles were obtained from various Indonesian journals related to animal science, i.e. (1) Media Peternakan, (2) Jurnal Pengembangan Peternakan Tropis, (3) Buletin Peternakan, (4) Jurnal Ilmu Ternak dan Veteriner, (5) Jurnal Peternakan Integratif, (6) Jurnal Agripet, (7) Jurnal Ilmu-ilmu Peternakan, and (8) Jurnal Ilmu Ternak. In each journal website, literature search was conducted with a keyword "sheep". All full text articles found were evaluated for their suitability to be included in the database. Minimum criteria for an article to be included in the database were that intial body weight (BW_0), average daily gain (ADG), dry matter intake (DMI) of sheep, and chemical composition of the ration used (at least crude protein content) were reported.

A total of 38 articles consisting of 137 data points (represented different dietary treatments) were integrated into the database (Mathius *et al.*, 1996; 1997; 1998; Thalib *et al.*, 1996; 2010; Lubis *et al.*, 1998; 2002; Mahyuddin, 2001; Duldjaman, 2004; Tarmidi, 2004; Adawiyah *et al.*, 2006; Puastuti *et al.*, 2006; Uhi, 2006; Supriati & Haryanto, 2007; Wiryawan *et al.*, 2007; Sudarman *et al.*, 2008; Supriyati, 2008; Tanuwiria & Ayuningsih, 2008; Thalib & Widiawati, 2008; Zain, 2009; Hartutik *et al.*, 2010; Hernaman *et al.*, 2011; Widiyanto *et al.*, 2011; 2012; Rimbawanto *et al.*, 2012; Ginting *et al.*, 2013; Ketaren *et al.*, 2013; Sitanggang *et al.*, 2013; Braymana *et al.*, 2014; Ekawati *et al.*, 2014; Khotijah *et al.*, 2014; Nababan *et al.*, 2014; Ndaru *et al.*, 2014; Wulandari *et al.*, 2014; Aqbari *et al.*, 2015; Simanjuntak *et al.*, 2015; Tiven *et al.*, 2015; Wati *et al.*, 2015). Different breeds (Priangan, fat-tailed and local) and sexes (male and female) were specified in the database. Initially there was also Sumatra sheep but the data were excluded due to scarcity of articles available (Puastuti *et al.*, 2010; Yulistiani *et al.*, 2011; 2013). Parameters included were dry matter intake (DMI), crude protein intake (CPI), ether extract intake (EEI), crude fiber intake (CFI), neutral detergent fiber intake (NDFI), acid detergent fiber intake (ADFI), total digestible nutrient intake (TDNI), average daily gain (ADG), gain to feed ratio (G:F), dry matter digestibility (DMD), rumen ammonia (NH_3) concentration and total volatile fatty acid (VFA) concentration. Parameters related to intake and ADG were expressed in relation to metabolic body weight (MBW, i.e $BW^{0.75}$) to account for variation due to different body weight of sheep. Data within a parameter were transformed into a similar measurement unit in order to allow direct analysis. Summary of the database used in the meta-analysis is presented in Table 1.

Data Analysis

Meta-analysis was performed by using a mixed model statistics (St-Pierre, 2001; Sauvant *et al*., 2008) in which different studies were considered as random effects whereas different breeds, sexes and nutrient intake were considered as fixed effects. Interaction between breed×sex, breed×intake, sex×intake and breed×sex×intake on dependent variables were initially tested. Any insignificant interactions were then removed from the statistical model. Significance of an effect was stated at P<0.05. Qualitative information such as study, breed and sex were stated in the class statement.

Table 1. Descriptive statistics of database used in meta-analysis

Parameter	Unit	Breed	N	Mean	SD	Min	Max
DMI	g/kg	Local	88	81.7	20.0	42.6	135
	MBW/d	Priangan	33	79.9	19.5	43.1	109
		Fat-tailed	16	69.9	9.89	59.6	93.8
CPI	g/kg	Local	88	10.8	3.20	4.65	21.1
	MBW/d	Priangan	33	11.4	2.76	5.90	17.5
		Fat-tailed	16	9.76	1.17	7.58	11.7
EEI	g/kg	Local	46	4.63	2.92	0.690	12.6
	MBW/d	Priangan	30	3.54	2.36	1.43	12.2
		Fat-tailed	4	5.27	0.459	4.67	5.67
CFI	g/kg	Local	46	18.2	7.59	7.46	39.4
	MBW/d	Priangan	30	14.0	7.41	5.41	27.8
		Fat-tailed	9	11.6	2.40	8.46	14.5
NDFI	g/kg	Local	34	40.6	7.84	28.5	54.4
	MBW/d	Priangan	5	43.7	3.32	40.3	48.0
		Fat-tailed	na	na	na	na	na
ADFI	g/kg	Local	28	23.1	5.63	14.3	31.7
	MBW/d	Priangan	5	27.0	3.87	22.6	32.0
		Fat-tailed	na	na	na	na	na
TDNI	g/kg	Local	46	53.3	17.9	17.1	95.8
	MBW/d	Priangan	26	49.7	12.5	27.6	67.2
		Fat-tailed	9	43.9	3.47	39.6	49.1
ADG	g/kg	Local	88	10.1	3.52	2.26	21.1
	MBW/d	Priangan	33	10.4	5.71	1.90	26.9
		Fat-tailed	16	10.0	5.09	3.14	16.7
G:F	%	Local	88	13.0	5.64	2.39	38.4
		Priangan	33	12.4	4.52	4.41	24.9
		Fat-tailed	16	15.0	8.46	4.61	24.4
DMD	%	Local	45	57.5	6.46	49.0	73.6
		Priangan	12	61.2	10.7	43.8	76.0
		Fat-tailed	16	74.1	5.52	64.5	83.1
NH_3	mmol/L	Local	6	9.06	1.57	7.10	10.9
		Priangan	12	6.55	2.70	3.06	11.0
		Fat-tailed	4	5.16	1.18	3.70	6.35
Total VFA	mmol/L	Local	6	114	35.6	73.5	150
		Priangan	8	111	7.69	95.0	118
		Fat-tailed	4	175	15.3	162	194

Note: N, number of data; SD, standard deviation; DMI, dry matter intake; CPI, crude protein intake; EEI, ether extract intake; CFI, crude fiber intake; NDFI, neutral detergent fiber intake; ADFI, acid detergent fiber intake; TDNI, total digestible nutrient intake; ADG, average daily gain; G:F, gain to feed; DMD, dry matter digestibility; NH_3, ammonia; VFA, volatile fatty acid; MBW, metabolic body weight ($BW^{0.75}$); na, data not available.

Weighting procedure was not applied in the present meta-analysis. An adjustment of dependent variable was performed to create a two-dimensional graphical presentation from multi-dimensional studies by adding the predicted dependent values with their corresponding residuals (St-Pierre, 2001). Maintenance and gain requirements for dry matter, energy and protein were determined by regressing ADG with DMI, TDNI and CPI, respectively. An intercept (where ADG= 0 g/kg MBW/d) and a slope (required nutrient intake per unit ADG) indicated maintenance and gain requirements, respectively. The P-value and coefficient of determination (R^2) were employed to assess the goodness-of-fit of the statistical model. All statistical analyses were conducted by using SAS Software version 9.1.

RESULTS

There was a positive relationship between sheep BW_0 and DMI (Figure 1); higher BW_0 led to a higher DMI (P<0.001). Interactions between breed, sex and BW_0 on DMI were not significant. When DMI was presented as percentage to BW_0, the relationship became negative (P<0.01; Figure 2). A positive linear relationship between ADG and DMI was observed (P<0.001; Figure 3); such relationship was similar among different breeds and sex (no significant interaction). Crude protein intake (CPI) positively influenced ADG (P<0.001) and there was an interaction between CPI and breed on ADG (P<0.05; Table 2). No significant relationships were found between ether extract intake (EEI), crude fiber intake (CFI) and neutral detergent fiber intake (NDFI) on ADG. Similar to CPI, total digestible nutrient intake (TDNI) positively influenced ADG and it was specific for each breed (P<0.001). The CPI also positively influenced gain to feed ratio (G:F; P<0.01). Interactions between EEI and sex on G:F (P<0.05) and CFI and breed on G:F (P<0.05) were significants. Both NDFI and ADFI negatively influenced G:F (P<0.05) and the interaction between breed, sex and ADFI on G:F was significant (P<0.01). Intake of nutrients was hardly influenced DMD, rumen ammonia and total VFA concentrations.

All sheep breeds (local, Priangan and fat-tailed) had similar energy requirement for maintenance (TDN_m) as shown by the relatively similar intercept values among the breeds (Figure 4). Energy requirement for gain (TDN_g) of Priangan breed was lower than other breeds; the breed required 0.860 g TDN for 1 g ADG. Fat-tailed and local breeds required 1.22 and 2.75 g TDN for 1 g ADG, respectively. All breeds also revealed relatively similar protein requirement for maintenance (CP_m), i.e. 6.27-6.47 g/kg MBW/d (Figure 5). Priangan breed required less CP for 1 g ADG (CP_g), i.e. 0.295 g. Requirements of CP_g for fat-tailed and local breeds were 0.336 and 0.497 g/g ADG, respectively. Based on the equations provided in Figure 4 and Figure 5, recommended dry matter, energy and crude protein intake for local, Priangan and fat-tailed sheep in Indonesia is presented in Table 3.

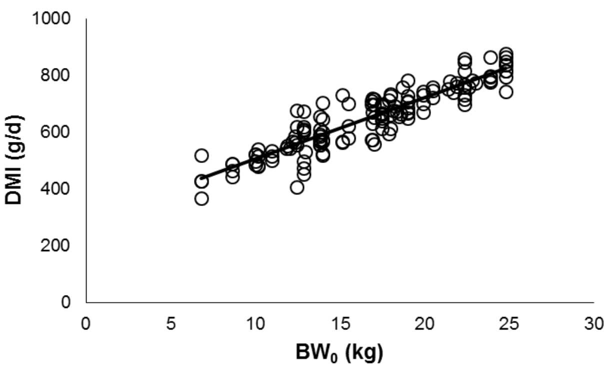

Figure 1. Relationship between initial body weight (BW_0, kg) and dry matter intake (DMI, g/d). DMI (g/d)= 288 + 21.6 BW_0 (kg) (N= 137; P<0.001; R^2= 0.829). All interactions between breed, sex, and BW_0 on DMI were insignificant.

DISCUSSION

Dry Matter Intake of Sheep

Feed intake is considered as a primary factor determining performance of livestock. A positive relationship

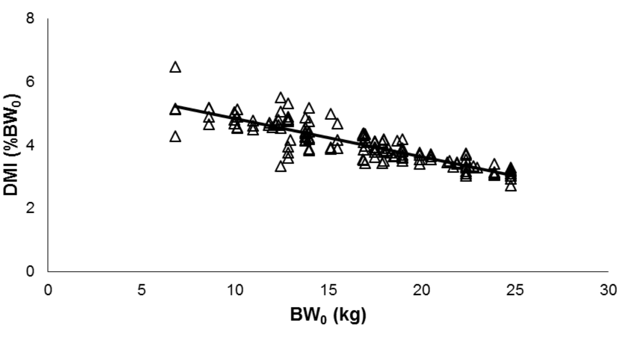

Figure 2. Relationship between initial body weight (BW_0, kg) and percentage of dry matter intake (DMI) to BW_0. DMI ($\%BW_0$)= 6.04 – 0.120 BW_0 (kg) (N= 137; P= 0.003; R^2= 0.746). All interactions between breed, sex, and BW_0 on DMI were insignificant.

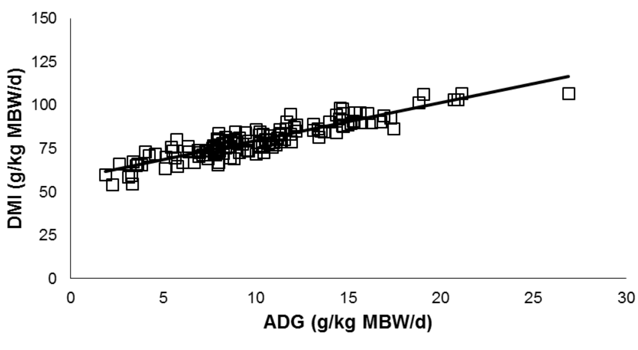

Figure 3. Relationship between dry matter intake (DMI, g/kg MBW/d) and average daily gain (ADG, g/kg MBW/d). DMI (g/kg MBW/d)= 57.6 + 2.20 ADG (g/kg MBW/d) (N= 137; P<0.001; R^2= 0.823). All interactions between breed, sex, and ADG on DMI were insignificant.

Table 2. Significancy (P-value) of relationship between independent and dependent variables

Dep	Indep	Breed	Sex	B×S	Indep	B×I	S×I	B×S×I
ADG	DMI	ns	ns	ns	0.005	ns	ns	ns
	CPI	ns	ns	ns	<0.001	0.037	ns	ns
	EEI	ns	ns	na	ns	ns	ns	na
	CFI	ns	ns	na	ns	ns	ns	na
	NDFI	ns	ns	ns	ns	ns	ns	ns
	ADFI	ns	ns	0.027	ns	ns	ns	ns
	TDNI	ns	na	na	<0.001	<0.001	na	na
G:F	DMI	ns	ns	ns	ns	ns	ns	ns
	CPI	ns	ns	ns	0.009	ns	ns	ns
	EEI	ns	ns	na	ns	ns	0.044	na
	CFI	ns	ns	na	ns	0.036	ns	na
	NDFI	ns	ns	ns	0.013	ns	ns	ns
	ADFI	ns	ns	<0.001	0.002	ns	ns	0.002
	TDNI	ns	na	na	ns	ns	na	na
DMD	DMI	ns	ns	ns	ns	ns	ns	ns
	CPI	ns	ns	ns	ns	ns	ns	ns
	EEI	ns	na	na	ns	ns	na	na
	CFI	ns	na	na	ns	ns	na	na
	NDFI	ns	ns	ns	ns	ns	ns	ns
	ADFI	ns	ns	na	ns	ns	ns	na
	TDNI	ns	na	na	ns	0.023	na	na
NH_3	DMI	ns	na	na	ns	ns	na	na
	CPI	ns	na	na	ns	ns	na	na
	EEI	ns	na	na	ns	ns	na	na
	CFI	ns	na	na	ns	ns	na	na
	NDFI	ns	na	na	ns	ns	na	na
	ADFI	na	na	na	ns	na	na	na
	TDNI	ns	na	na	ns	ns	na	na
Total VFA	DMI	ns	na	na	ns	ns	na	na
	CPI	ns	na	na	ns	ns	na	na
	EEI	ns	na	na	ns	ns	na	na
	CFI	ns	na	na	ns	ns	na	na
	NDFI	ns	na	na	ns	ns	na	na
	ADFI	na	na	na	ns	na	na	na
	TDNI	ns	na	na	ns	ns	na	na

Note: Dep, dependent variable; Indep (I), independent variable; B, breed; S, sex. DMI, dry matter intake; CPI, crude protein intake; EEI, ether extract intake; CFI, crude fiber intake; NDFI, neutral detergent fiber intake; ADFI, acid detergent fiber intake; TDNI, total digestible nutrient intake; ADG, average daily gain; G:F, gain to feed; DMD, dry matter digestibility; NH_3, ammonia; VFA, volatile fatty acid; ns, not significant at P<0.05; na, data not available.

between sheep BW_0 and DMI was also observed in a meta-analysis study of Riaz *et al.* (2014). It was observed not only in sheep but also in other domestic ruminant species such as goat, cattle and buffalo. However, when DMI was presented proportionally to BW_0 then the relationship turned to be negative. It has been known that intake is directly related to maintenance requirement. With increasing body weight, maintenance requirement per unit of BW decrease and thus feed intake relative to BW decrease as well (Riaz *et al.*, 2014). Using an equation presented in Figure 2, for instance, a sheep with 20 kg BW may require a DMI of 3.64% BW. The value is within the range of sheep DMI with similar BW, i.e. 2.86-3.91% BW as recommended by NRC (2007). Such NRC (2007) DMI recommendation range depends on ADG of sheep and energy concentration in the diet. The result was also in close agreement with Kearl (1982) who recommended that DMI of sheep (20 kg BW) ranged from 2.8%-3.6% BW.

Feed intake of ruminants is affected by a number of factors, i.e. dietary, animal and environmental factors (Nikkhah, 2014). Dietary factors affecting feed intake are comprised of feed physical and chemical properties, processing and fermentation rhythms. Animal factors affecting intake include parity, lactation stage (in the case of dairy animals), hormones, body fat stores and distribution, cellular hypoxia and energy flow, and production characteristics, whereas environmental

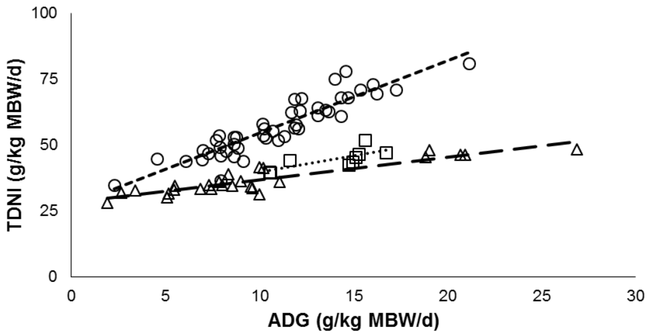

Figure 4. Relationship between total digestible nutrient intake (TDNI, g/kg MBW/d) and average daily gain (ADG, g/kg MBW/d) of local (-o-), Priangan (-Δ-) and fat-tailed (-□-) sheep breeds.

Local breed : TDNI (g/kg MBW/d)= 27.0 + 2.75 ADG (g/kg MBW/d)
(N= 46; P<0.001; R^2= 0.833)

Priangan breed: TDNI (g/kg MBW/d)= 28.2 + 0.860 ADG (g/kg MBW/d)
(N= 26; P<0.001; R^2= 0.829)

Fat-tailed breed: TDNI (g/kg MBW/d)= 27.5 + 1.22 ADG (g/kg MBW/d)
(N= 9; P= 0.019; R^2= 0.568)

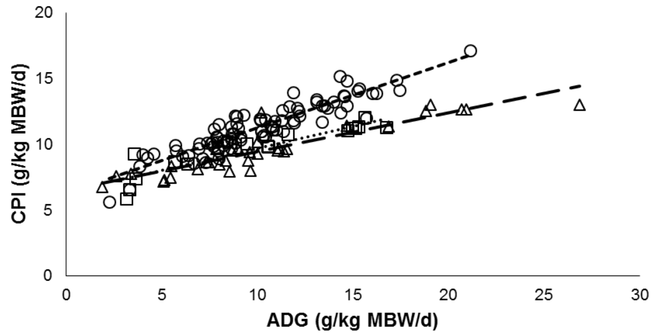

Figure 5. Relationship between crude protein intake (CPI, g/kg MBW/d) and average daily gain (ADG, g/kg MBW/d) of local (-o-), Priangan (-Δ-) and fat-tailed (-□-) sheep breeds.

Local breed : CPI (g/kg MBW/d)= 6.27 + 0.497 ADG (g/kg MBW/d)
(N= 88; P<0.001; R^2= 0.844)

Priangan breed : CPI (g/kg MBW/d)= 6.47 + 0.295 ADG (g/kg MBW/d)
(N= 33; P<0.001; R^2= 0.823)

Fat-tailed breed : CPI (g/kg MBW/d)= 6.33 + 0.336 ADG (g/kg MBW/d)
(N= 16; P<0.001; R^2= 0.851)

Table 3. Recommended dry matter, energy (total digestible nutrient, TDN) and crude protein (CP) intake for local, Priangan and fat-tailed sheep in Indonesia

BW (kg)	ADG (g/d)	Local (g/d)			Priangan (g/d)			Fat-tailed (g/d)		
		DM	TDN	CP	DM	TDN	CP	DM	TDN	CP
10	0	324	152	35	324	159	36	324	155	36
	50	434	289	60	434	202	51	434	216	52
	100	544	427	85	544	245	66	544	277	69
	150	654	564	110	654	288	81	654	338	86
15	0	439	206	48	439	215	49	439	210	48
	50	549	343	73	549	258	64	549	271	65
	100	659	481	97	659	301	79	659	332	82
	150	769	618	122	769	344	94	769	393	99
20	0	545	255	59	545	267	61	545	260	60
	50	655	393	84	655	310	76	655	321	77
	100	765	530	109	765	353	91	765	382	93
	150	875	668	134	875	396	105	875	443	110
25	0	644	302	70	644	315	72	644	307	71
	50	754	439	95	754	358	87	754	368	88
	100	864	577	120	864	401	102	864	429	104
	150	974	714	145	974	444	117	974	490	121
30	0	738	346	80	738	361	83	738	353	81
	50	848	484	105	848	404	98	848	414	98
	100	958	621	130	958	447	112	958	475	115
	150	1068	759	155	1068	490	127	1068	536	132

Note: BW, body weight; ADG, average daily gain.

factors that affect intake are feeding systems and strategies, housing management, ambient temperature and humidity (Nikkhah, 2014). Further, Lewis & Emmans (2010) observed that feed intake of sheep were affected by body weight, breed, sex and feed composition. Numerous factors have been attempted to predict dry matter intake of ruminants, and body weight of the animals is considered as one of the most reliable factors for such prediction. Salah *et al.* (2014), for instance, estimated DMI from BW with a coefficient determination of 0.91. The NRC (2007) also used BW in the terms of standard reference weight and relative size to estimate intake of sheep with a number of correction factors such as sheep physiological state and diet quality (legume content and quality of the legume).

Energy Requirement of Sheep

Expression of energy intake found in feeding experiments using sheep in Indonesia was generally in the form of TDN. This energy system is actually not ideal and therefore, current system has to be moved towards metabolizable energy (ME) or even net energy (NE) system (NRC, 2007; Van Duinkerken *et al.*, 2011; Van Amburgh *et al.*, 2015). Further, TDN data from various diets were obtained by estimations from their chemical composition and seldomly derived experimentally; such predictions may not be accurate since no study so far, to our knowledge, has validated the relationship between estimated TDN and measured TDN in the country. It is apparent that in the future we should update our energy system. Measurement of gross energy (GE) is presently available in many laboratories related to animal nutrition in Indonesia. Derivation of digestible energy (DE) value is relatively simple by combining GE intake and digestibility coefficient of the diet. Determination of ME requires a certain equipment to measure loss of energy as methane. In the case of unavailable or insufficient data of methane emissions across various dietary regimes, a number of equations to estimate methane emissions from sheep are available (Sejian *et al.*, 2011; Vetharaniam *et al.*, 2015) and may be used to derive ME from DE data.

Requirement of TDN obtained in the present study is apparently higher in comparison to the recommendation of NRC (2007). For instance, a growing lamb with BW of 20 kg and ADG 100 g/d requires 300 g TDN/d (NRC, 2007). At similar BW and ADG, local sheep, Priangan and fat-tailed breeds require 530, 353 and 382 g TDN/d, respectively. Nevertheless, Kearl (1982) suggested that sheep with such BW and ADG required 470 g TDN/d which is in accordance with our present result. Salah *et al.* (2014) reported that, by using a meta-analysis study, ME_m requirements of tropical and temperate sheep are 423.7 and 361.2 kJ/kg MBW, respectively. These value are equal to 28.1 and 23.9 g TDN/kg MBW/d, respectively, taking into consideration that 1 kg TDN= 4.4 Mcal DE and ME= DE × 0.82 (NRC, 2007). Our TDN_m values ranged from 27.0 to 28.2 g/kg MBW/d which were quite comparable to the value of ME_m of tropical sheep (Salah *et al.*, 2014). Further, ME_g of tropical and temperate sheep are 17.6 and 16.4 kJ/g ADG, respectively (Salah *et al.*, 2014), which are equal to 1.166 and 1.086 g TDN/g ADG. In comparison to such recommendation, our TDN_g value was lower for Priangan breed but higher for local and fat-tailed breeds.

Our results suggested a higher TDN requirement in comparison to NRC (2007) standard. To make the recommendation, NRC (2007) employed a database from 31 references with 156 observations from 1,875 sheep in which the sheep genotype presented was of temperate origin such as Dorset, Rambouillet, St. Croix, Hampshire, Suffolk and many others. On the contrary, our database was developed by using sheep genotype of tropical origin and thus apparently more appropriate with the recommendation of Kearl (1982). Tropical genotypes generally are not selected for muscle deposition and, hence, tend to be fatter as compared to those of temperate genotypes (Chay-Canul *et al.*, 2011). In consequence, tropical genotypes require more energy for ADG than the temperate genotypes. Further, under high temperature conditions prevailing in the tropics, sheep require more energy to dissipate body heat and therefore increase the energy requirement of the animal (CSIRO, 2007). Another factor that may explain such higher energy requirement of sheep obtained in this study is the diet. Tropical sheep are generally fed with agricultural by-products that rich in fiber contents (Zain, 2009; Ginting *et al.*, 2013; Ndaru *et al.*, 2014). Such fibrous feeds may increase heat production, visceral energy consumption, energy needed for intake and chewing, energy expenditure, and finally total energy requirement of ruminants (Salah *et al.*, 2014).

Comparing among different sheep breeds evaluated in the present meta-analysis study, it was clear that the order of TDN_g requirement was as follow: Priangan < fat-tailed < local. This indicates that Priangan sheep is more efficient in converting energy intake into body mass as compared to the other two breeds, and local breed is the least efficient. This result is in agreement with Sumantri *et al.* (2007) who observed that body weight and body size of Priangan (Garut) sheep were higher as compared to other breeds, including local sheep from Jonggol and fat-tailed sheep from various locations (Madura, Donggala, Kisar, Rote, and Sumbawa). It seems that genetic potential of Priangan sheep is better since the breed was a cross between local, Merino and fat-tailed sheep (Inounu, 2011), thus inherited all the excellent characteristics from the three breeds. Aditionally, Priangan sheep have been genetically selected for superior agility and accompanied with good feeding and raising practices particularly in Garut region (Inounu, 2011). On the contrary, local sheep receive much less attention with regard to genetic selection, breeding, feeding and management practices thus contributing to their low production merit. Body compositions of different sheep breeds apparently also influence their TDN_g requirements. Baihaqi & Herman (2012) reported that carcass of Priangan breed had more muscle and less fat at mature live weight than that of fat-tailed breed. At a slaughter weight of 32.5 kg, Priangan breed contained 4.85 kg muscle and 2.28 kg fat, whereas fat-tailed breed contained 4.49 kg muscle and 2.73 kg fat. Similarly, at a slaughter weight of 40 kg, muscle contents in Priangan and fat-tailed breeds were 5.70 and 5.03 kg, respectively, while their fat contents were 2.66 and 3.70 kg, respectively (Baihaqi & Herman, 2012). Since fat synthesis requires more energy, it is therefore obvious that fat-tailed sheep require more TDN_g than that of Priangan.

Protein Requirement of Sheep

Expression of protein intake found in feeding experiments using sheep in Indonesia was in the form of crude protein (CP). This system is less accurate and current system has to be shifted to metabolizable protein (MP) system or its equivalent (NRC, 2007; Van Duinkerken *et al.*, 2011; Das *et al.*, 2014; Owens *et al.*, 2014; Van Amburgh *et al.*, 2015). The old CP system has a main disadvantage, i.e. it does not differentiate between protein requirement of rumen microbes and protein requirement of the host animal (Das *et al.*, 2014). The MP system, conversely, addresses both the need of N for rumen microbes and postruminal need of amino acids for maintenance and growth of the host ruminant (Owens *et al.*, 2014). By employing the MP system, basic goals in protein nutrition of ruminants can be achieved, i.e. (1) to meet rumen degradable protein (RDP) requirement of rumen microbes for maximum carbohydrate digestion and microbial protein synthesis, (2) to meet MP requirement of host animal for maintenance, growth, optimum health, and reproduction with minimum intake of rumen undegradable protein (RUP), and (3) to meet MP and amino acids requirements of the host animal for a desired production level with minimum dietary CP (Das *et al.*, 2014). Even though MP system is preferable as compared to CP system, such application may be difficult due to limited data available like the case in Indonesia. An alternative solution is to predict MP from CP; dietary MP concentration ranges from 64 to 80% of CP with diets of 0 to 100% of RUP, respectively (NRC, 2007). So if the proportion of RUP is known then MP can be estimated. But if RUP is unknown then using CP system is still acceptable (Owens *et al.*, 2014).

As of TDN, CP requirement of Indonesian sheep obtained by using meta-analysis approach is higher than the NRC (2007) recommendation. Local, Priangan and fat-tailed sheep with BW 20 kg and ADG 100 g/d would require 109, 91 and 93 g CP/d, respectively, whereas NRC (2007) recommends 69-76 g CP/d that depends on RUP proportion in the diet; higher RUP proportion leads to lower CP requirement. Accordingly, Kearl (1982) recommended 72 g CP/d for sheep with similar BW and ADG. Salah *et al.* (2014) reported that digestible CP (DCP) requirements of tropical and temperate sheep genotypes were similar; DCP requirement for maintenance (DCP_m) and gain (DCP_g) was 2.8 g/kg MBW and 0.2 g/g ADG, respectively. Assuming a CP digestibility of 70% in mixed diets consumed by sheep (Zagorakis *et al.*, 2015; Aemiro *et al.*, 2017), the CP_m and CP_g requirements become 4.0 g/kg MBW and 0.286 g/g ADG, respectively. Our CP_m and CP_g values for all sheep breeds evaluated were higher in comparison to those of Salah *et al.* (2014). It has to be noted that such CP requirements may have to be adjusted according to variation in dietary CP digestibility; among the factors that influence the digestibility or nitrogen retention are nitrogen intake, faecal nitrogen excretion and urinary nitrogen excretion (Schuba *et al.*, 2017). Further, presence of dietary factors that influence the proportion between RDP to RUP may also change CP_g requirement. Among them are polyphenols or tannins that shift towards more RUP proportion since the compounds are able to form complexes with dietary protein and protect the nutrient from microbial degradation in the rumen (Jayanegara *et al.*, 2013; 2015).

Higher CP requirement obtained in this study probably is a reflection of the difference between tropical and temperate sheep breeds in which the tropical breed has generally lower growth potential (Chay-Canul *et al.*, 2011) as previously described. High environmental temperature in the tropics may also explain such high CP_m and CP_g requirements obtained in the current study. It has been described that high temperature is associated with an increase of absorbed amino acid requirement for growth in ruminants (Salah *et al.*, 2014). Lower CP_g requirement of Priangan breed confirms superiority of the breed as compared to fat-tailed and local breeds (Sumantri *et al.*, 2007; Inounu, 2011).

CONCLUSION

Each sheep breed in Indonesia has specific TDN and CP requirements. Although energy and protein requirements for maintenance (TDN_m and CP_m) are similar across sheep breeds, different sheep breeds have significantly different energy and protein requirements for gain (TDN_g and CP_g). Priangan sheep requires less TDN_g and CP_g in comparison to fat-tailed and local breeds, and local breed possesses higher TDN_g and CP_g requirements than those of the fat-tailed. Further studies are required to validate the current results of energy and protein requirements for Indonesian sheep.

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