Effects of gender and age on energy use by young Boer goats

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ABSTRACT

Boer goats (7/8 and 1/8 Spanish breed) were used to characterize effects of gender and age on the ME requirement for maintenance (ME_m). There were eight animals of each gender, doelings, intact males, and wethers castrated at 2 mo of age. Kids were weaned at 3.7 mo and thereafter consumed a 50% concentrate pelleted diet ad libitum while in group pens at most times. Measurement periods consisted of three segments of 12, 10, and 4 days with consumption ad libitum and near ME_m and while fasting, respectively. Maintenance segment measures began at 4.9, 7.8, 11.7, and 14.8 mo of age in periods 1, 2, 3, and 4, respectively. Feed intake data, feces and urine collections, and a calorimetry system were used to determine ME intake and heat energy (HE). The ME_m estimate was based on fasting HE and the slope (k_m) of the regression of recovered energy (RE) against ME intake with intake near ME_m and while fasting, and k_g was RE with ad libitum intake relative to ME intake above ME_m . BW (kg) during the maintenance segment was 20.6, 30.8, 46.5, and 57.1 for doelings, 25.9, 40.1, 67.3, and 76.9 for males, and 23.1, 35.1, 53.9, and 65.0 for wethers in periods 1, 2, 3, and 4, respectively ($SE = 1.85$). k_m was similar among genders and periods ($P > 0.05$); 70.2%, 69.5%, and 69.7% for doelings, males, and wethers, respectively; $SE = 1.25$). Fasting HE and ME_m were affected by gender $\times$ period interactions ($P < 0.001$). Fasting HE (kJ/kg BW^{0.75}) was 277, 272, 281, and 281 for doelings, 288, 327, 334, and 398 for males, and 274, 303, 274, and 305 for wethers ($SE = 10.1$); ME_m (kJ/kg BW^{0.75}) was 382, 390, 399, and 420 for doelings, 412, 469, 492, and 569 for males, and 384, 417, 426, and 439 for wethers in periods 1, 2, 3, and 4, respectively ($SE = 14.2$). k_g tended ($P = 0.067$) to vary among genders (61.5%, 48.1%, and 52.7% for doelings, males, and wethers, respectively; $SE = 3.91$). In conclusion, ME_m was not greatly different between doelings and wethers and increased for both as the study progressed, whereas that for males was greater, with the difference increasing considerably as age rose.

1. Introduction

Energy and nutrient requirements of livestock are difficult to address both in terms of original research and for committees charged with summarizing available information and providing recommendations to be of value in many areas. This is particularly challenging for goats because of the wide range of conditions they are able to survive in and produce under and the multitude of factors affecting their requirements.

One of the limitations of the nutrient requirement recommendations for goats of Sahlu et al. (2004) and NRC (2007), as well as of other scientific committees, is potential influence of gender. Research on which energy requirements of goats presented by NRC (2007) was based dealt with databases of treatment mean observations constructed from publications available in the literature that contained suitable intake and performance information. This approach was taken so that the databases were broad and application of the findings could be

widespread, albeit with appropriate adjustments. This is converse to focus on a few studies under a limited number of conditions with variable methodologies that could lead to questionable extrapolation to different settings. However, as addressed by Sahlu et al. (2004) and NRC (2007), an excessive number of publications used in constructing the databases did not clearly address gender and there were inadequate studies available that specifically targeted potential effects of gender. Thus, recommendations of NRC (2007) to address gender differences in the energy requirement for maintenance were ones previously proposed for other ruminant species, namely similar values for females and wethers and ones 15% greater for intact males.

Need for research to address this information void and evaluate these assumptions has been frequently stated since publication of NRC (2007), notable examples being Sahlu et al. (2009) and Tedeschi et al. (2010). In this regard, recently Almeida et al. (2015) did not observe differences in ME_m among female, male, and wether Saanen goats over a 15-kg range in BW and time period of 3.5–4 mo by comparative

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slaughter with different levels of feed intake. The primary objective of the present experiment was to characterize ME_m of Boer goats over wide ranges of age and BW and managed under fairly conventional production conditions.

2. Materials and methods

2.1. Animals, periods, and measures

The experimental protocol was approved by the Langston University Animal Care and Use Committee. Twenty-four meat goat kids born in the study of Tovar-Luna et al. (2011), 7/8 Boer and 1/8 Spanish, were used. Eight males were castrated at 65 days of age, and there were eight males left intact and eight doelings. Kids were weaned at 111 ± 0.2 days of age, treated for internal parasites, and housed in a facility with individual 1.05×0.55 m elevated pens with a plastic-coated expanded metal floor until measurements were completed in period 2. Water was available free-choice and feed was offered at 08:00 and 18:00 h. Thereafter, animals were situated by gender in 6.1×5.6 m pens in an enclosed building that had a 6.1×1.35 m area with a concrete floor and a 6.1×4.25 m unpaved floor area when measurements were not underway. Automated waterers were used, pine shavings were periodically added as bedding, and each pen had an automated feeding unit allowing ad libitum intake (MK 3 FIRE, Feed Intake Recording Equipment; Osborne Industries, Inc., Osborne, KS, USA).

Most measurement periods consisted of three segments of 12, 10, and 4 days with consumption ad libitum and near the ME requirement for maintenance (ME_m) and while fasting, respectively. Feed offered was gradually increased for 1 wk after fasting to avoid digestive upset. Maintenance phase measures began at 148 ± 1.5 , 236 ± 1.3 , 355 ± 1.1 , and 450 ± 1.99 days (i.e., 4.9, 7.8, 11.7, and 14.8 mo, respectively). For the first part of each segment, goats were housed individually in the 1.05×0.55 m elevated pens. Thereafter during collection of feces and urine and gas exchange measurements, goats were situated in metabolism crates (0.7×1.2 m; plastic-coated expanded metal floor).

The diet was offered at approximately 120% of consumption on the preceding few days when intake was ad libitum. The rate of feeding ME near the ME_m requirement was 489 kJ/kg BW^{0.75}, and the amount of DM offered was based on assumed concentrations of 60% TDN and 9.1 MJ/kg ME for the diet shown in Table 1. However, the ad libitum intake segment of period 4 was omitted because intake was not markedly different from that near the assumed ME_m requirement. In addition, subsequent measures occurred at 631 ± 2.6 and $826 \pm$ days of age (20.8 and 27.2 mo of age, respectively) in periods 5 and 6, respectively. However, because of different management conditions after period 4, with housing by gender in small outside pens and free-choice feeding of the same diet, BW declined and was lower during period 5 measures than in period 4. As a consequence, ME_m estimates were lower than earlier and, thus, are not reported. Body weight during measurements in period 6 had increased considerably from that in period 5 and was similar or greater than values in period 4. Period 6 ME_m estimates are presented, but because of a lesser number of observations (7, 5, and 5 for doelings, males, and wethers, respectively) are only briefly compared with values in period 4.

Excreta collection occurred on the last 5 days of ad libitum and ME_m segments, and gas exchange measures were on the final 2 days of the segments. Animals began measurement periods sequentially so that there was one or two of each gender assessed for gas exchange at the same time. Urine was acidified with 20 ml of 0.2 (vol/vol) H₂SO₄ placed in each collection vessel to maintain pH below 3.0. Composite samples of feces and urine were formed by collecting 10% daily aliquots, and samples were stored at -20°C . Feed was sampled daily during measurements to form four composite samples at each age. Feed and fecal samples were analyzed for DM (ID 9560.03; AOAC, 2006), ash (942.05; AOAC, 2006), nitrogen (Leco TruMac CN, St. Joseph, MI), NDF

Table 1

Ingredient composition of a 50% concentrate pelleted diet and chemical composition of feedstuffs fed to growing meat goats.

Item	
Ingredient (% as fed basis)	
Dehydrated alfalfa	19.98
Cottonseed hulls	29.07
Cottonseed meal	15.99
Ground corn	15.99
Wheat middlings	9.99
Pelletizing agent	5.00
Trace mineralized salt ^a	0.50
Salt	0.50
Yeast	1.00
Calcium carbonate	0.95
Ammonium chloride	1.00
Vitamin A premix ^b	0.02
Rumensin 80 premix ^c	0.01
Chemical composition	
OM (% DM)	92.2 ± 0.06
CP (% DM)	16.4 ± 0.15
NDF (% DM)	44.8 ± 0.44
Gross energy (MJ/kg DM)	17.6 ± 0.06

^a Contained 95–98% NaCl and at least 0.24% Mn, 0.24% Fe, 0.05% Mg, 0.032% Cu, 0.011% Co, 0.007% I, and 0.005% Zn.

^b Contained 66,200 IU/kg.

^c 17.6% monensin.

with use of heat stable amylase (Van Soest et al., 1991) and containing residual ash (filter bag technique of ANKOM Technology Corp., Fairport, NY), and gross energy (GE) using a bomb calorimeter (Parr 6300; Parr Instrument Co., Inc., Moline, IL). Urine samples were analyzed for DM (lyophilization), and nitrogen and GE concentrations in lyophilized urine samples were determined as described above.

Body weight was determined at the beginning of each segment and at the start and end of the 2 days of gas exchange measurements. Gas exchange occurred in a room with four metabolism cages fitted with head-boxes of an indirect, open-circuit respiration calorimetry system (Sable Systems International, Las Vegas, NV, USA). Heat energy (HE) was determined as in other studies (Puchala et al., 2007, 2009). Oxygen concentration was analyzed using a fuel cell FC-1B O₂ analyzer (Sable Systems International), and CH₄ and CO₂ concentrations were measured with infrared analyzers (CA-1B for CO₂ and MA-1 for CH₄; Sable Systems International). Prior to gas exchange measurements, analyzers were calibrated with gases of known concentrations. Ethanol combustion tests were performed to ensure complete recovery of O₂ and CO₂ produced with the same flow rates as used during measurements. Heat energy was determined according to the Brouwer (1965) equation. Energy lost in CH₄ was total CH₄ emitted in L/day $\times$ 39.5388 kJ/L (Brouwer, 1965), and ME was the difference between DE and the sum of energy in urine and methane. Recovered energy (RE) was the difference between ME intake (MEI) and HE. Heat energy was expressed relative to average BW^{0.75} within the 2-day assessment periods. Average daily gain between BW at birth and period 1 and between subsequent periods was determined based on average BW during the gas exchange measurement period with intake near the ME_m requirement.

2.2. Calculations and statistical analyses

There were some missing observations because of factors including equipment malfunction, occasional health issues, length of measurement period constraints in regards to other experimentation with the same facilities and equipment, data collection mishaps, etc. It was felt preferable in terms of accuracy to include all potential observations as shown in Table 2 rather than only those for animals having estimates for all variables in each period.

The efficiency of energy use for ME_m (k_m) was determined by

Table 2
Numbers of observations.

Item ^c	Gender	Intake level	Period ^{a,b}			
			1	2	3	4
BW	Doeling		8	8	8	7
	Male		7	7	7	7
	Wether		7	8	8	6
ADG	Doeling		8	8	8	7
	Male		7	7	7	7
	Wether		7	7	8	6
Intake and digestion measures	Doeling	Ad libitum	8	7	8	
	Doeling	Near ME _m	8	7	8	7
	Male	Ad libitum	8	7	8	
	Male	Near ME _m	8	7	7	7
	Wether	Ad libitum	8	7	8	
	Wether	Near ME _m	8	7	8	7
FHP, k _m , and ME _m	Doeling		8	8	8	7
	Male		7	7	7	7
	Wether		7	7	8	6
	Doeling		7	8	8	
k _g	Male		7	7	7	
	Wether		6	6	8	

^a Measurement periods consisted of three segments of 12, 10, and 4 days for consumption ad libitum and near the ME requirement for maintenance and while fasting, respectively.

^b Maintenance segment measures began at 4.9, 7.8, 11.7, and 14.8 mo of age, respectively.

^c FHP = fasting heat production; k_m = efficiency of ME utilization for maintenance; ME_m = ME requirement for maintenance; k_g = efficiency of ME utilization for gain.

regressing RE against ME intake (MEI) during ME_m and fasting segments, with ME_m of each animal derived from dividing fasting HE (FHE) by k_m. Metabolizable energy used for gain (ME_g) in periods 1, 2, and 3 with ad libitum intake was estimated as the difference between MEI and ME_m. Recovered energy with ad libitum intake used for tissue gain (RE_g) regressed against ME_g with ad libitum intake and when fed near maintenance, assuming that ME_g and RE_g were 0, yielded the efficiency of energy use for tissue energy accretion (k_g). This estimate of k_g is the same as simply dividing RE_g by ME_g when animals consumed the diet ad libitum. Relatedly, regressing RE_g against ME_g with ad libitum intake and intake near ME_m without setting RE_g at 0 with near ME_m intake resulted in some unrealistic k_g estimates (i.e., negative or above 100%). Most likely this was because of the application of an efficiency of energy utilization based on both tissue mobilization while fasting and primarily use of dietary ME for maintenance when fed near ME_m to any differences between the estimate of ME_m and actual MEI when fed near ME_m.

Data were analyzed with mixed effects models (Littell et al., 1996) with the repeated measure of period and random effect of animal within gender. Fixed effects were gender, period, and their interaction.

Table 3
Effects of gender and age on BW and ADG of Boer goats.

Item	Effect P value ^a				Period contrast P values ^b			Period ^{c,d}				SE
	GN	PR	GN*PR		Linear	Quadratic	Cubic	1	2	3	4	
BW (kg)	< 0.001	< 0.001	< 0.001	Doeling	< 0.001	0.875	0.015	20.6	30.8	46.5	57.1	1.85
				Male	< 0.001	0.027	< 0.001	25.9	40.1	67.3	76.9	
				Wether	< 0.001	0.624	0.001	23.1	35.1	53.9	65.0	
ADG (g)	< 0.001	< 0.001	< 0.001	Doeling	0.575	0.134	0.101	118	116	134	104	9.9
				Male	0.073	< 0.001	< 0.001	149	162	227	107	
				Wether	0.555	0.123	0.041	139	134	158	122	

^a GN = gender; PR = period.

^b Linear, quadratic, and cubic effects of period.

^c Measurement periods consisted of three segments of 12, 10, and 4 days for consumption ad libitum and near the ME requirement for maintenance and while fasting, respectively.

^d Maintenance segment measures began at 4.9, 7.8, 11.7, and 14.8 mo of age in period 1, 2, 3, and 4, respectively.

Main effects and their means were addressed when the interaction was nonsignificant ($P > 0.05$) and interaction means were presented when the interaction was significant ($P < 0.05$). Separation of BW, ADG, and energy measure means was through orthogonal contrasts for linear and quadratic effects of period or increasing age. It was assumed that ages were equally spaced, since testing of the actual spacing with the IML procedure of SAS (2004) indicated negligible effect. To evaluate effects of level of intake on digestibility measures, estimates with intake near the ME_m requirement in period 4 were omitted, with period 4 ME_m data analyzed by the GLM procedure of SAS (2004). This model included gender, period, level of intake, two-way interactions, and the three way interaction, with the repeated measure of period $\times$ intake level and means separation by least significant difference with a protected F-test ($P < 0.05$).

Homogeneity of variance was evaluated with the Bartlett test of SAS (2004). To evaluate energetically optimal body size as described by Hannon and Murphy (2016), HE of different periods in MJ/day while fasting and consuming feed ad libitum and near ME_m and the ME_m estimate were regressed against linear, quadratic, and cubic functions of BW without and with model inclusion of gender and level of intake. Pearson correlation coefficients were determined for some energy measures with the CORR procedure of SAS (2004).

3. Results

3.1. BW and ADG

There were interactions ($P < 0.001$) between gender and period in BW and ADG (Table 3). As expected, increases in BW as the trial advanced ranked males > wethers > doelings. The interaction in ADG was primarily because of relatively high values for males in periods 2 and 3, particularly the latter. Body weight in period 6 for doelings (57.7 ± 2.13 kg) and males (74.0 ± 2.49 kg) was similar to values in period 4, although wethers were slightly heavier ($P = 0.005$) in period 6 (70.7 ± 2.20 kg).

3.2. Intake and digestion

There were no three-way interactions in intake or digestibility measures ($P > 0.05$; Tables 4 and 5). Dry matter intake was affected by interactions between level of intake and gender and period ($P \leq 0.01$). The former interaction was because of greater gender differences when intake was ad libitum than near ME_m, at least particularly reflective of differences in BW and ADG. The interaction in DM intake appeared due primarily to a less than expected value in period 2 with ad libitum intake, which corresponds to similar ADG from birth to period 1 and between periods 1 and 2 compared with ADG from period 2–3. Digestibility of DM was greater for wethers than for males ($P < 0.05$), with an intermediate value for doelings ($P > 0.05$), and was

Table 4
P values for effects of gender and age on intake and digestion in Boer goats.

Item	Effect P values ^a						
	GN	PR	GN*PR	IL	GN*IL	PR*IL	GN*PR*IL
DM							
Intake (g/day)	0.002	< 0.001	0.083	< 0.001	0.008	0.001	0.770
Digestion (%)	0.031	0.969	0.151	< 0.001	0.659	0.217	0.686
Digestion (g/day)	0.03	< 0.001	0.004	< 0.001	0.049	< 0.001	0.341
OM							
Intake (g/day)	0.001	< 0.001	0.081	< 0.001	0.008	0.001	0.770
Digestion (%)	0.013	0.566	0.221	< 0.001	0.637	0.167	0.714
Digestion (g/day)	0.003	< 0.001	0.005	< 0.001	0.050	< 0.001	0.351
Gross energy							
Intake (MJ/day)	0.001	< 0.001	0.065	< 0.001	0.009	0.001	0.777
Digestion (%)	0.014	0.451	0.236	< 0.001	0.638	0.006	0.754
Digestion (MJ/day)	0.004	< 0.001	0.003	< 0.001	0.067	< 0.001	0.338
Methane							
MJ/day	0.096	< 0.001	0.879	0.062	0.936	0.012	0.895
% gross energy intake	0.840	< 0.001	0.880	< 0.001	0.763	0.003	0.990
ME							
Intake (MJ/day)	0.002	< 0.001	0.002	< 0.001	0.020	< 0.001	0.118
Intake (kJ/kg BW ^{0.75})	0.843	< 0.001	0.059	< 0.001	0.508	< 0.001	0.101
Concentration (MJ/kg DM)	0.252	0.133	0.451	< 0.001	0.973	0.674	0.838
CP							
Intake (g/day)	0.001	< 0.001	0.025	< 0.001	0.009	< 0.001	0.788
Digestion (%)	0.164	< 0.001	0.252	0.314	0.672	0.823	0.075
Digestion (g/day)	0.003	< 0.001	0.001	< 0.001	0.050	< 0.001	0.224
NDF							
Intake (g/day)	0.001	< 0.001	0.110	< 0.001	0.007	0.002	0.792
Digestion (%)	0.008	< 0.001	0.341	< 0.001	0.473	0.001	0.706
Digestion (g/day)	0.005	< 0.001	< 0.001	< 0.001	0.493	0.003	0.083
Nitrogen balance (g/day)	0.003	< 0.001	0.039	< 0.001	0.097	0.072	0.603

^a GN = gender; PR = period; IL = intake level.

7.2% units greater ($P < 0.05$) with intake near the ME_m requirement than ad libitum ($P < 0.05$). Digestible DM intake was affected by all two-way interactions ($P \leq 0.05$), with those involving intake level due to corresponding ones in DM intake. However, the gender $\times$ period interaction was mainly because of similar values for wethers in periods 1 and 2 in contrast to greater values in period 2 for males and doelings.

Results for OM, GE, and NDF intake and digestibilities in periods 1, 2, and 3 were similar to those for DM, except for interactions between intake level and period in digestibility of GE and NDF ($P = 0.01$; Tables 4 and 5). These interactions appeared due mainly to lower values in period 3 vs. 1 with ad libitum intake compared with similar values among periods with intake near ME_m. Intake of ME relative to BW^{0.75} was affected by an interaction between level of intake and period ($P < 0.001$), which was because of a greater value for period 1 vs. 2 and 3 with ad libitum intake and lower and similar values among periods with intake near ME_m. Intake of DM was 1038 ± 31.1 , 1280 ± 42.3 , and 21186 ± 81.2 g/day, DM digestibility was 64.2 ± 0.59 , 64.6 ± 0.96 , and $62.2 \pm 1.98\%$, and digestible DM intake was 666 ± 20.5 , 826 ± 27.1 , and 743 ± 66.9 g/day for doelings, males, and wethers, respectively, in period 4. The diet ME concentration in periods 1, 2, and 3 was 8.5% greater with intake near ME_m than ad libitum.

Intake of CP was affected ($P \leq 0.03$) by each two-way interaction, similar to many of the aforementioned interactions (Tables 4 and 5). Only period affected ($P < 0.001$) CP digestion, with values ranking period 2 < 1 < 3. Digestible CP intake was also impacted by all two-way interactions ($P \leq 0.05$). Differences among genders and between intake levels were relatively greater in period 3 vs. periods 1 and 2 and the difference between intake levels was slightly greater for males than for doelings and wethers. Nitrogen balance estimates were relatively high and suggest unaccounted for N loss(es). Nonetheless, as expected the value was greater with ad libitum vs. restricted feed intake

($P < 0.001$) and the magnitude of difference between males and doelings and wethers was much greater in period 3 than in periods 1 or 2.

3.3. Energy measures

Ruminal methane emission in MJ/day was similar between levels of intake in periods 1 and 2 and greater for ad libitum intake than for intake near ME_m in period 3 (Tables 4 and 5). Relative to GE intake, methane emission was much greater for ad libitum vs. intake near ME_m in periods 1 and 2 than in period 3.

Heat energy while fasting and consuming feed near ME_m and the ME_m estimate were affected by gender $\times$ period interactions ($P < 0.05$), without any factor impacting k_m ($P > 0.05$; Table 6). The ME_m estimate for each gender linearly increased ($P < 0.02$) as period advanced, although values were fairly similar among genders in period 1 and increased relatively more as time progressed for males than for doelings or wethers. The ME_m values in period 6 (424, 595, and 435 kJ/kg BW^{0.75} for doelings, males, and wethers, respectively; SE = 38.5) were similar to those in period 4 ($P = 0.819$) and the gender $\times$ period interaction was not significant ($P = 0.913$).

Heat energy with ad libitum intake was greater ($P < 0.05$) for males than for doelings and wethers and was less in periods 2 and 3 than in period 1 (linear and quadratic P values of < 0.001 and $= 0.002$, respectively). The estimate of ME_g was not different among genders ($P = 0.741$) and was greatest among periods in period 1 (linear and quadratic changes, $P < 0.001$). The k_g tended ($P = 0.067$) to differ among genders, numerically ranking doelings > wethers > males. Also, k_g changed quadratically with increasing period ($P = 0.049$), decreasing from period 1–2 and then increasing in period 3 to a value similar to that in period 1.

Variation in FHE among animal-period observations differed among

Table 5
Effects of gender and age on intake and digestion in Boer goats.

Item	Interaction ¹		Gender ²			SE	Period ^{3,4}			SE	Intake level ⁵		
	GN	IL	D	M	W		1	2	3		AL	MN	SE
DM													
Intake (g/day)	D										1126	707	50.6
	M										1494	889	
	W										1225	776	
		AL					1161	1127	1569	38.6			
		MN					569	772	1031				
Digestion (%)			63.6 ^{ab}	62.6 ^a	64.8 ^b	0.544	63.6	63.8	63.7	0.50	60.1	67.3	0.42
Digestion (g/day)	D						458	551	714	33.3	675	473	31.0
	M						584	671	953		879	593	
	W						559	566	788	749	527		
		AL					683	671	950	22.8			
		MN					385	521	687				
OM													
Intake (g/day)	D										1039	652	46.6
	M										1377	820	
	W										1129	715	
		AL					1062	1037	1445	35.5			
		MN					526	711	950				
Digestion (%)			64.9 ^{ab}	63.5 ^a	66.0 ^b	0.53	64.5	64.7	65.2	0.41	61.1	68.6	0.41
Digestion (g/day)	D						430	516	675	31.0	635	446	28.8
	M						546	624	894		821	555	
	W						522	530	745	702	495		
		AL					638	626	895	21.2			
		MN					361	487	648				
Gross energy													
Intake (MJ/day)	D										19.89	12.49	0.892
	M										26.39	15.72	
	W										21.64	13.71	
		AL					20.11	19.67	28.14	0.681			
		MN					9.95	13.48	18.49				
Digestion (%)			63.0 ^b	61.5 ^a	64.0 ^b	0.52	57.4	58.5	60.3	0.71			
Digestion (MJ/day)	D						67.2	67.7	65.8	0.572			
	M						7.83	9.56	12.76				
	W						9.91	11.51	16.84				
		AL					9.54	9.71	14.04	0.393			
		MN					11.51	11.41	16.92				
							6.67	9.12	12.17				
Methane													
MJ/day			0.93	1.17	1.02	0.075							
		AL					0.64	1.04	1.59	0.075			
		MN					0.63	1.07	1.25				
% gross energy intake			5.9	5.8	6.1	0.29							
		AL					3.1	5.2	5.7	0.37			
		MN					6.5	8.3	6.8				
ME													
Intake (MJ/day)	D						6.80	8.09	10.85	0.494	10.19	6.98	0.456
	M						8.77	9.77	14.40		13.32	8.64	
	W						8.52	8.16	11.71		11.24	7.68	
		AL					10.47	9.83	14.44	0.342			
		MN					5.59	7.51	10.20				
Intake (kJ/kg BW ^{0.75})			655	668	653	18.5							
		AL					1014	682	707	19.9			
		MN					528	520	500				
Concentration (MJ/kg DM)			9.49	9.27	9.57	0.126	9.48	9.28	9.58	0.115	9.06	9.83	0.096
CP													
Intake (g/day)	D						117	137	196	9.0	184	116	8.2
	M						154	168	263		244	146	
	W						136	138	217		200	127	
		AL					181	175	272	6.3			
		MN					90	120	179				
Digestion (%)			64.9	64.0	66.2	0.77	63.9	60.5	70.7	0.68	65.4	64.7	0.58
Digestion (g/day)	D						74	84	138	6.0	123	75	5.6
	M						95	100	186		159	95	
	W						91	83	155	134	85		
		AL					117	105	194	4.3			
		MN					57	73	125				
NDF													
Intake (g/day)	D										515	325	23.3

(continued on next page)

Table 5 (continued)

Item	Interaction ¹		Gender ²			SE	Period ^{3,4}			SE	Intake level ⁵			SE
	GN	IL	D	M	W		1	2	3		AL	MN		
Digestion (%)	M										688	410		
	W										564	358		
		AL					526	531	710	17.8				
		MN	47.8	46.7	51.1	0.90	260	365	467					
Digestion (g/day)		AL					36.8	44.3	42.7	1.15				
		MN					55.6	59.1	52.6					
	D						140	205	234	11.5				
	M						175	244	318					
Nitrogen balance (g/day)	W						187	220	269					
		AL					191	230	301	7.9				
		MN					144	216	246					
											16.1	9.0	0.54	
	D						7.8	8.9	17.4	1.10				
	M						9.7	11.0	24.2					
	W						8.4	7.8	17.6					

^{a,b} Gender means without a common superscript letter differ ($P < 0.05$).

¹ GN = gender; IL = intake level.

² D = doeling; M = male; W = wether.

³ Measurement periods consisted of three segments of 12, 10, and 4 days for consumption ad libitum and near the ME requirement for maintenance and while fasting, respectively.

⁴ Maintenance segment measures began at 4.9, 7.8, and 11.7 mo of age in periods 1, 2, and 3, respectively.

⁵ AL = ad libitum; MN = near the ME requirement for maintenance.

genders ($P < 0.001$), which was also the case for animal-gender observations in the different periods ($P = 0.004$; Table 7). Based on overall SD for gender and period and for the genders in each period, variability was greater for males than for doelings and wethers and greatest among periods in period 4. Variability in k_m was also greater in periods 1 and 4 vs. periods 2 and 3 but was not different among genders ($P = 0.748$). Overall, variability in ME_m also was greatest among genders for males, although differences were somewhat greater in periods 2 and 3 than in periods 1 and 4. Variability in k_g also differed among genders, being lowest for doelings.

The P values of BW, BW^2 , and BW^3 in regressions against HE in MJ/day at the three different levels of intake were 0.055, 0.225, and 0.162,

with an R^2 of 0.598. Inclusion of fixed effects of level of intake, gender, and their interaction ($P < 0.001$, $P < 0.001$, and $P < 0.001$) resulted in P values of 0.033, 0.828, and 0.560 for BW, BW^2 , and BW^3 , respectively, with a greater R^2 of 0.938. Regressions of HE by level of intake and gender resulted in nonsignificant coefficients for the linear, quadratic, and cubic BW functions ($P \geq 0.099$). However, similar to the regression noted above, inclusion in the model of gender ($P < 0.001$) resulted in P values of 0.025, 0.211, and 0.133 for BW, BW^2 , and BW^3 , respectively, with a R^2 of 0.927.

Fasting HE in period 1 was correlated with that in period 3 ($r = 0.55$; $P = 0.008$). There were correlations between FHE in period 2 and periods 3 ($r = 0.59$; $P = 0.004$) and 4 ($r = 0.65$; $P = 0.003$) and between

Table 6
Effects of gender and age on energy measures of Boer goats.

Item ⁶	Effect P value ¹			GN	Period contrast P values ²			Gender ³				Period ^{4,5}				
	GN	PR	GN*PR		Linear	Quadratic	Cubic	D	M	W	SE	1	2	3	4	SE
HE (kJ/kg BW ^{0.75})																
Fasting	< 0.001	< 0.001	< 0.001	D	0.576	0.774	0.549					277	272	281	281	10.1
				M	< 0.001	0.170	0.030					288	327	334	398	
				W	0.128	0.918	0.004					274	303	274	305	
Intake near ME_m	< 0.001	< 0.001	0.003	D	0.223	0.719	0.512					419	432	429	436	10.2
				M	< 0.001	0.834	0.223					444	480	494	534	
				W	0.089	0.287	0.825					426	442	452	447	
Ad libitum intake	< 0.001	< 0.001	0.672		< 0.001	0.002		540 ^a	635 ^b	569 ^a	11.8	636	551	557		11.4
k_m	0.909	0.126	0.330		0.097	0.406	0.147	70.2	69.5	69.7	1.25	71.3	70.9	67.7	69.3	1.27
ME_m (kJ/kg BW ^{0.75})	< 0.001	< 0.001	< 0.001	D	0.016	0.567	0.764					382	390	399	420	14.2
				M	< 0.001	0.381	0.083					412	469	492	569	
				W	0.002	0.425	0.594					384	417	426	439	
ME_g (kJ/kg BW ^{0.75})	0.741	< 0.001	0.066		< 0.001	< 0.001		398	367	383	30.6	618	259	268		27.7
k_g	0.067	0.049	0.169		0.502	0.017		61.5	48.1	52.7	3.91	58.8 ^b	47.8 ^a	55.8 ^{ab}		3.37

^{a,b} Gender means without a common superscript letter differ ($P < 0.05$).

¹ GN = gender; PR = period.

² Linear, quadratic, and cubic effects of period.

³ D = doeling; M = male; W = wether.

⁴ Measurement periods consisted of three segments of 12, 10, and 4 days for consumption ad libitum and near the ME requirement for maintenance and while fasting, respectively.

⁵ Maintenance segment measures began at 4.9, 7.8, 11.7, and 14.8 mo of age in period 1, 2, 3, and 4, respectively.

⁶ HE = heat energy; ME_m = ME requirement for maintenance; k_m = efficiency of ME utilization for maintenance; ME_g = ME requirement for gain; k_g = efficiency of energy utilization for gain.

Table 7
Homogeneity of variance for energy measures of Boer goats.

Item ^a	Bartlett test P value		Gender Bartlett test P value for periods				Period	Gender SD			Period SD			
	Gender	Period	1	2	3	4		D	M	W	1	2	3	4
FHE (kJ/kg BW ^{0.75})	< 0.001	0.004	0.198	0.023	0.065	0.005	Mean	17.6	55.3	23.2	29.6	31.4	36.6	59.9
							1	19.1	40.5	29.4				
							2	11.6	33.7	15.5				
							3	22.3	38.0	14.6				
							4	17.4	48.5	11.8				
k _m	0.748	0.009									6.5	4.4	4.2	7.9
ME _m (kJ/kg BW ^{0.75})	< 0.001	< 0.001	0.171	0.001	0.196	0.897	Mean	33.2	74.1	37.2	27.0	46.2	52.1	86.8
							1	14.3	31.4	25.5				
							2	25.6	50.0	11.1				
							3	27.8	50.5	27.2				
							4	51.0	62.0	55.3				
k _g	0.004	0.378					Mean	9.5	16.8	20.6				

^a FHE = fasting heat energy; k_m = efficiency of ME utilization for maintenance; ME_m = ME requirement for maintenance; k_g = efficiency of energy utilization for gain.

period 3 and 4 measures ($r = 0.62$; $P = 0.004$). No significant correlations were noted among period k_m measures. Nonetheless, ME_m estimates in each period were correlated, with r of 0.66 ($P = 0.001$), 0.53 ($P = 0.011$), 0.63 ($P = 0.004$), 0.75 ($P < 0.001$), 0.79 ($P < 0.001$), and 0.76 ($P < 0.001$) between periods 1–2, 1–3, 1–4, 2–3, 2–4, and 3–4, respectively. In contrast to the lack of relationship between k_m in different periods, k_g in period 3 was moderately correlated with estimates in periods 1 ($r = 0.35$; $P = 0.006$) and 2 ($r = 0.30$; $P = 0.017$). Estimates of k_m and k_g in the same period were not significantly related, as was true for ME_m and k_g except for a moderate negative correlation in period 2 ($r = -0.26$; $P = 0.048$).

4. Discussion

4.1. Diet, ADG, and BW

The diet has been previously used in meat goat buck performance tests of Langston University (Hu et al., 2012) and studies of Ngwa et al. (2007, 2009). Even with the segments of intake near ME_m, fasting, and realimentation, it facilitated moderate ADG through period 4 and greater ADG by males than doelings and wethers in three and two periods, respectively. It is not clear why the magnitude of the gender difference was greatest in period 3. Similar ADG among genders in period 4 may reflect the relatively high stage of maturity and smaller differences in composition of tissue accreted than earlier, particularly in periods 1 and 2. Relatedly, BW in periods 1, 2, and 3 was 34–36, 52–54, and 81–88% of that in period 4, respectively. Hence, with growth rates of this experiment, it would appear that the genders were at fairly similar stages of maturity.

The lack of significant cubic effects of BW in regressions against HE in MJ/day suggest that optimal body size, as addressed by Hannon and Murphy (2016), was not exceeded at any age. This is in accordance with moderate ADG, implying that fat accretion was not particularly high. Although, composition of the whole body and tissue accreted would have most likely differed among genders to some extent as expected based on studies such as Almeida et al. (2015, 2016). That a level of ad libitum feed intake adequately above that near ME_m was not achieved in period 4 but could be earlier also supports BW not greater than optimal size.

4.2. Intake and digestion

Magnitudes of difference in DM intake between levels of intake (i.e., ad libitum and near ME_m) for the genders (averaging 419, 605, and 449 g/day for doelings, males, and wethers, respectively) were in accordance with expected differences in potential for BW gain and nutrient and energy use. It is not clear why the difference between

levels of intake was less in period 2 (355 g/day) than periods 1 (592 g/day) and 3 (538 g/day), although this could have resulted in compensatory growth potential and highest ADG in period 3. Slightly lower digestibility for males than for doelings, except of CP, presumably relates to shorter ruminal digesta residence time because of high DM intake by males (Leite et al., 2015a, 2015b). This also should be primarily responsible for considerably lower digestibility, other than CP, with ad libitum than near ME_m intake.

4.3. ME_m

Some sets of recommendations of nutrient requirements for small ruminants entail lower ME_m for mature than for growing animals or decreases with increasing age and stage of maturity (e.g., SCA, 1990; NRC, 2007; Small Ruminant Nutrition System, Tedeschi et al., 2010). It is possible that with greater ages this would have been noted in the present experiment as well. However, here ME_m of doelings and wethers in fact linearly increased at a relatively slow rate as the experiment progressed, with values at each time fairly similar between genders. This latter aspect agrees with many recommendations, including those of NRC (2007), AFRC (1998), SCA (1990), and Tedeschi et al. (2010).

Greater ME_m for males vs. doelings and wethers in periods 2, 3, and 4, as well as in period 6, is in general agreement with assumptions of some sets of recommendations, such as a 15% difference (SCA, 1990; NRC, 2007), but the magnitude increased with advancing time. Factors responsible for this finding are unclear, yet some potentially involved issues can be addressed. One consideration is that composition of the whole body and tissue being accreted was probably fairly similar among genders in period 1 at a young age and when BW was not markedly different (Almeida et al., 2015), with greater differences anticipated in periods 2 and 3 (Almeida et al., 2016). Perhaps with the relatively high stage of maturity in period 4 during the period of measurement the composition of any accreted tissue was similar among genders. In regards to the substantial gender difference in period 4, animals were maintained in gender groups in the same facility, although the male pen was not adjacent to that of these or other female goats, without direct fence line contact. Furthermore, period 4 measures occurred in mid- to late summer when some female goats at the University farm may have begun cycling, which could have caused behavior of males that contributed to elevated HE and ME_m. However, that ME_m of males was numerically 26 kJ/kg BW^{0.75} greater in period 6 vs. 4 suggests that if this factor did have influence in period 4, a similar effect occurred approximately 1 yr later in period 6.

Without considering periods 4 or 6, the ME_m of males averaged 14.5% greater than the average for doelings and wethers. Relating to the magnitude of difference, there was consideration given for applying

unique levels of intake near ME_m to the genders. But, if a level greater for males than doelings or wethers had been used, such as 15% of SCA (1990) and NRC (2007), gender ME_m estimates could be considered confounded. Moreover, use of the same near ME_m level of intake might have lessened male HE compared with a higher near ME_m intake level, thereby increasing k_m and minimizing ME_m and differences from doelings and wethers.

Based on the homogeneity of variance analysis, males appeared considerably more variable in ME_m than females and wethers because of FHE rather than k_m . This might relate to differences among individuals in rates of maturation, encompassing impact on body composition as well as other physiological conditions affecting basal metabolic rate. Differences in such factors seem less important at a young age as in period 1 than later when older.

4.4. k_m and k_g

The k_m estimates were in close accordance with prediction based on the AFRC (1998) equation of $(0.35 \times q) + 0.503$, with q being ME intake relative to GE intake as a fraction (i.e., 0.511 and 0.556 with intake ad libitum and near ME_m , respectively) and predicted values of 68.2% and 69.8%, respectively. Estimates of k_g were considerably more variable than those of k_m , concomitant with numerical differences among genders in line with findings of Almeida et al. (2015) and a lower value in period 2 than 1, for which factors responsible are unclear. Moreover, the AFRC (1998) equation of $(0.024 \times q) + 0.465$ predicted k_g of 48%, similar to that noted for males and period 2 but lower than for other estimates. The k_g determined by Almeida et al. (2015) for Saanen goats initially at 9.2 mo of age and 30 kg BW varied among genders as seen in the present experiment, although magnitudes of difference were much greater (i.e., 55%, 32%, and 40% for doelings, males, and wethers, respectively). Almeida et al. (2015) also applied these k_g to the composition of empty BW gain at the highest BW, yielding ME_g (53.8, 52.4, and 46.9 MJ/kg empty BW gain for doelings, males, and wethers, respectively) much greater than values suggested by NRC (2007) even for mature goats. Perhaps this involves relatively high fat deposition at that time as well as low estimates of ME_m relative to other procedures, as addressed later. Although corresponding values could be determined in the present experiment, their value would be questionable considering that ADG encompasses periods of time with intake near ME_m , while fasting, and during realimentation.

4.5. Energy measure relationships

Relationships noted between energy measures in the periods entail influence of maintenance over time of differences among genders and individuals within gender. Nonetheless, it would appear that animals with relatively low, moderate, or high ME_m tended to remain as such throughout the study largely because of differences in FHE rather than k_m . Pelletizing and the associated small particle size of the diet might have contributed to little variability among animals in mass and energy use by the gastrointestinal tract (Goetsch, 1998) to minimize differences in k_m . Although only one goat breed was used, the lack of correlation between k_m and k_g , as was also generally true for ME_m and k_g , could support the postulate that the greater capacity for growth and mature size of Boer goats compared with other meat breeds such as Spanish of the USA is not accompanied by a greater ME_m requirement (Ngwa et al., 2009; Asmare et al., 2012).

4.6. Study conditions

Little attention has been given thus far to absolute values of FHE, k_m , ME_m , and k_g because of many influencing factors that make direct comparisons of estimates from different studies challenging. For example, the 412 kJ/kg $BW^{0.75}$ ME_m estimate of Almeida et al. (2015) for Saanen doelings, males, and wethers from 30 to 45 kg BW

with ad libitum intake was similar to some values in the present experiment but lower and greater than others. The k_m of Almeida et al. (2015; 62.7%) was less than found in this experiment as well. Animal age and activity and estimation procedures are among conditions that may have contributed to such differences.

The nature of animal activity and behavior could influence energy measures in experiments like these. During most of this study animals were in groups to simulate common production settings with free movement and socialization when not used for measurements, whereas housing in the study of Almeida et al. (2015) was not specifically stated though could have been on an individual animal basis. Animals in the present experiment were not grazing; however, some previous studies suggest impact of the experimental setting on basal metabolic rate throughout the day regardless of the specific activity an animal might be engaged in at a particular point in time (Patra et al., 2008a, 2008b; Tovar-Luna et al., 2011; Brassard et al., 2016).

Animals of the different genders were of similar age in this study and that of Almeida et al. (2015), but pre-trial management apparently differed. That is, BW of genders in the present experiment was allowed to vary, but that of Saanen goats of each gender used by Almeida et al. (2015) was 30 kg at an average initial age of 9.2 mo. This implies an ADG of approximately 96 g from birth at an assumed BW of 3 kg to the start of the experiment for each gender, suggesting a lower pre-trial plane of nutrition for males that could have impacted later measurements (Asmare et al., 2006; Tovar-Luna et al., 2007; Helal et al., 2011; Goetsch et al., 2017).

With estimation of FHE by Almeida et al. (2015) based on RE determined with ad libitum intake and levels 25% and 50% less, both FHE and k_m should be less than in experiments like the present because of different contributions to HE of metabolism of energy from the diet and mobilized tissue at the different levels of intake, even though quality of the diet used by Almeida et al. (2015) may have been greater. In addition, subjecting the same animals in the present experiment to the different levels of intake in sequential segments would have had effects different from those with constant levels of intake over entire, relatively short-term experiments such as that of Almeida et al. (2015). As supported by findings of Tovar-Luna et al. (2010) with lactating Alpine goats, measures in the latter part of the intake near ME_m segment of the present experiment were most likely still influenced by earlier ad libitum intake, with elevated HE compared with continuous near ME_m intake, which was presumably also true for the subsequent fasting segment. Hence, the approach of the present experiment should yield higher ME_m estimates than comparative slaughter with three levels of intake without fasting, with concomitant effect on k_g and ME_g .

5. Conclusions

As age of Boer goats increased from approximately 5 to 15 mo with a moderate rate of growth, ME_m was fairly similar for doelings and wethers and increased with advancing time at a relatively slow rate (e.g., 4 kJ/kg $BW^{0.75}$ per month). The ME_m of males at 5, 8, and 12 mo was 14.5% greater than the average of doelings and wethers, but with a greater rate of increase with increasing age and a much greater value at 15 mo (i.e., 32%).

Conflicts of interest

There are no conflicts of interest.

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