Effects of stage of lactation and dietary concentrate level on energy utilization by Alpine dairy goats

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ABSTRACT

Twenty-four lactating and 13 nonlactating Alpine goats were used to determine effects of stage of lactation and dietary concentrate level on energy utilization. Diets comprising 60 or 20% concentrate (60%C and 20%C, respectively) were consumed ad libitum by lactating animals and at a level of intake near maintenance by nonlactating animals. Measurement periods were d 25 to 31 (early), 87 to 94 (mid), and 176 to 183 (late) of lactation. Eleven observations were made in early and mid lactation for each diet, and 8 and 7 were made in late lactation for the 60%C and 20%C diets, respectively. Efficiency of metabolizable energy (ME) use for maintenance (66.9, 71.4, and 61.1% for early, mid, and late lactation, respectively) and the maintenance ME requirement (479, 449, and 521 kJ/kg of BW^{0.75} for early, mid, and late lactation, respectively) determined with nonlactating animals differed among stages of lactation. The efficiency of ME use for maintenance was similar between diets, but the maintenance requirement tended to be greater for the 60%C than for the 20%C diet (504 vs. 463 kJ/kg of BW^{0.75}). The latter difference may have involved greater ME intake for the 60%C diet, resulting in a slightly greater difference between ME intake and total heat energy for the 60%C compared with the 20%C diet (11 vs. –8 kJ/kg of BW^{0.75}). Intake of ME by lactating goats was greater for the 60%C than for the 20%C diet (18.6 vs. 16.3 MJ/d). Recovered energy in lactation from mobilized tissue tended to be greater for the 60%C than for the 20%C diet (8.44 vs. 6.55 MJ/d) and differed among stages of lactation (2.60, 1.59, and 1.13 MJ/d in early, mid, and late lactation, respectively). Recovered energy in tissue gain was similar among stages of lactation and between diets and was not different from 0. Efficiency of use of dietary ME for lactation differed among stages of lactation (59.5, 51.9, and 65.4% for early, mid, and late lactation, respectively) and tended to be greater

for the 60%C than for the 20%C diet (64.2 vs. 54.9%). The efficiency of use of dietary ME for maintenance and lactation was similar among stages of lactation and was greater for the 60%C compared with the 20%C diet (64.3 vs. 60.9%). Predicted milk yield from National Research Council requirements was reasonably accurate. In conclusion, using data of nonlactating goats to study energy utilization for maintenance in lactation has limitations. Efficiency of energy use by lactating dairy goats consuming diets high in concentrate appears greater than that by goats consuming diets low in concentrate. Despite differences in nutrient requirement expressions, observations of this study support National Research Council recommendations of energy requirements of lactating dairy goats.

Key words: dairy goat, lactation, energy

INTRODUCTION

Energy requirements of lactating dairy goats recommended by NRC (2007) are based on the study of Nsahlai et al. (2004) involving a database of treatment means from the literature. These observations were of goats with intake at or near the ad libitum level. Although for dairy cattle one efficiency of energy utilization is assumed for the sum of the maintenance need and that for milk production (NRC, 2001), Nsahlai et al. (2004) employed an efficiency of dietary ME used for maintenance based on an equation of AFRC (1998) accounting for diet metabolizability. Also, a constant efficiency of utilization of mobilized tissue energy for lactation (AFRC, 1993, 1998) was assumed to derive one efficiency with which dietary ME is used for lactation. Information available for observations in the database employed by Nsahlai et al. (2004) was not conducive to thorough consideration of potential effect of factors such as dietary concentrate level or stage of lactation.

Dietary forage level affects several conditions that influence efficiency of energy metabolism (NRC, 2007). For example, Ngwa et al. (2009) indicated that based on tissue mass, energy expended by the metabolically active gastrointestinal tract was greater for a diet with

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Table 1. Composition of diets¹ consumed by lactating Alpine goats (% of DM)

Item	Diet	
	20	60
Ingredient		
Cottonseed hulls	20.21	20.42
Ground alfalfa hay	60.00	20.19
Ground corn	7.00	32.85
Soybean meal	3.00	11.31
Blood meal	0.39	1.04
Fish meal	0.77	3.57
Molasses	2.50	2.52
Fat ²	3.30	3.33
Dicalcium phosphate	1.45	1.00
Limestone	0.00	0.91
Ammonium sulfate	0.28	0.28
Sodium bicarbonate	0.00	1.12
Vitamin premix ³	0.56	0.56
Trace mineralized salt ⁴	0.56	0.56
Magnesium oxide	0.33	0.34
Chemical composition		
Ash	10.9	10.2
NDF	43.1	31.3
CP	17.5	20.4

¹Diets: 20 = 20% concentrate; 60 = 60% concentrate.

²Megalac (Church and Dwight Inc., Lakewood, NJ).

³Contained 2,200 IU/g of vitamin A, 1,200 IU/g of vitamin D₃, and 2.2 IU/g of vitamin E.

⁴Contained 95 to 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.

60% forage compared with a diet with 40% forage. Likewise, in the same study internal fat mobilization and the concentration of energy in mobilized or accreted tissue varied with stage of lactation. Therefore, objectives of this study were to determine effects of dietary concentrate or forage level and stage of lactation on energy utilization by Alpine dairy goats.

MATERIALS AND METHODS

Animals, Diets, and Measurement Times

The protocol for this experiment was approved by the Langston University Animal Care and Use Committee (Langston, OK). Thirty-seven Alpine does were used, 24 lactating and 13 nonpregnant and nonlactating. Seven lactating does were primiparous and 17 were in the second or third lactation. Of the dry does, 4 had 1 previous lactation and 9 had 2 or 3 past lactation periods. Primiparous does were 2.0 yr of age (SEM = 0.05) when the experiment began, and multiparous does were 3.7 yr of age (SEM = 0.18). As kidding occurred, at 3 d after parturition does in sets of 2 were randomly assigned to either a 60% concentrate diet (**60%C**) or a 20% concentrate diet (**20%C**; Table 1). Does were vaccinated against clostridial organisms and treated

for internal parasites (Valbazen, SmithKline Beecham Animal Health, West Chester, PA) before kidding.

During most of the experiment, does were housed in pens (4 × 6 m) in a building with individual feeding by Calan gates (American Calan Inc., Northwood, NH) and continual access to water. Artificial lighting was used from the beginning of milking at 0500 h until after milking all animals of the Langston University dairy herd at approximately 1800 h. The experiment began in mid May and, thus, occurred in late spring, summer, and fall. The building included windows for ventilation and fans for greater air circulation during warm periods. Patra et al. (2009) conducted an experiment in the same building and noted similar temperature and relative humidity as outside.

Twelve lactating does were fed each diet, 7 dry does received the 60%C diet, and the remaining 6 dry does received the 20%C diet. Intake by lactating does was ad libitum, with diets offered at 110% of consumption on the preceding few days at 0800 and 1500 h (70 and 30% of the daily allocation, respectively). Dry does were fed amounts of diets to provide ME near a requirement for maintenance (**ME_m**; AFRC, 1998). Assumed dietary ME concentrations were based on feedstuff composition of NRC (1981). Equal amounts of diets were fed to dry does at 0800 and 1500 h.

On d 18, 80, and 169 of lactation, sets of 3 or 4 lactating or dry does were moved sequentially to metabolism crates equipped with head boxes for adaptation to conditions similar to those used later for calorimetry measurements. After 7 d of adaptation, total feces and urine collections and calorimetry measures were taken over a 7-d period.

Nutrient Balance

Fecal and urine collections occurred on d 25 to 31 (early), 87 to 94 (middle), and 176 to 183 (late) of lactation. Feces were collected in wire-screen baskets placed under the floor of the metabolism crates, and urine was collected through a funnel into plastic buckets containing 50 mL of 12% (vol/vol) hydrochloric acid. Subsamples (20%) of feces and urine were collected daily and stored at -20°C. Feed, feed refusal, and fecal samples were first dried in a forced-air oven at 55°C for 48 h and then ground to pass a 1-mm screen. Feed and feed refusal samples were analyzed for DM, ash, N, gross energy (**GE**) (AOAC, 1990), and NDF (filter bag technique; Ankom Technology Corp., Fairport, NY), and fecal samples were analyzed for DM, ash, GE, N, and NDF. Urine samples were assayed for DM (lyophilization; model CRVP-195P Dura Stop, FTS Systems, Stone Ridge, NY), and N and GE concentrations were determined with dried samples. Does were milked

twice daily at 0500 and 1600 h. Milk samples were collected at both times on d 1, 4, and 7 of the 3 collection periods. Samples were analyzed for fat, protein, lactose, and TS at the certified DHIA Laboratory for Goats at Langston University. Milk composition was determined with a MilkoScan 400 analyzer (Foss Electric, Hillerød, Denmark) that was calibrated monthly. Additional milk samples (approximately 50 g) were collected and frozen at -20°C until being lyophilized to determine DM concentration. Dry samples were used to determine GE.

Calorimetry Measures

Gas exchange measurements for both lactating and dry does were performed the last 2 d of the 7-d period for fecal and urine collections. Does were moved into a calorimetry room with 4 metabolism crates fitted with head boxes. The indirect open-circuit calorimetry system was described previously by Tovar-Luna et al. (2007). The concentration of O_2 was analyzed using a fuel cell FC-1B O_2 analyzer (Sable Systems, Las Vegas, NV). Concentrations of CO_2 and CH_4 were measured using infrared analyzers (FC-1B for CO_2 and MA-1 for CH_4 ; Sable Systems). Air was first analyzed for CH_4 and then for CO_2 and O_2 . Prior to the gas exchange measurements, validity and accuracy of expired CO_2 and inspired O_2 flows were checked with ethanol combustion with the same flow rates as used during measurements. Before each test, analyzers were calibrated with reference gas mixtures (19.5 and 20.5% O_2 , 0.0 and 1.5% CO_2 , and 0.0 and 0.3% CH_4 , with 2 concentrations of each gas). Temperature (20 – 23°C) in the calorimetry room was maintained with a window air conditioning-heating unit (Carrier, Farmington, CT), and humidity was 50 to 55% through use of a dehumidifier (Whirlpool, Benton Harbor, MI). The natural photoperiod was mimicked by use of fluorescent lights. After measurements for nonlactating animals while being fed, there was a 4-d fasting period with gas exchange measurement during the final 2 d.

Calculations

Intake of ME (**MEI**) was calculated from GE intake and energy losses in feces, urine, and CH_4 . Energy expenditure or heat energy (**HE**) was estimated based on the Brouwer (1965) equation from O_2 consumption and CO_2 and CH_4 production on days of gas exchange measurement, as well as urinary N excretion. The ME_m was determined from fasting or resting HE of nonlactating does divided by the efficiency of ME utilization for maintenance (k_m , expressed in %), which was 100 minus the slope of the regression of HE against MEI

when fed and fasted. Averages of fasting HE and ME_m in kilojoules per kilogram of $\text{BW}^{0.75}$ and k_m of nonlactating does were assumed for lactating does fed the same diets at corresponding times of measurement.

Recovered energy (**RE**) was determined as the difference between MEI and HE. Recovered energy in milk (i.e., lactation; **RE_l**) was based on milk yield and concentrations of DM and GE. When RE_l was equal to or less than RE, no tissue mobilization was assumed. If RE_l was greater than RE, the difference was milk energy arising from mobilized tissue (**RE_{lt}**). Tissue energy mobilized to produce RE_{lt} (**ME_{lt}**) and HE associated with use of mobilized tissue energy for milk synthesis (**HE_{lt}**) were determined assuming an efficiency of 84% (AFRC, 1998). The difference between RE_l and RE_{lt} was milk energy from dietary ME (**RE_{ld}**). It was assumed that all mobilized tissue energy was used for lactation, with energy used for maintenance derived exclusively from dietary ME. When RE was greater than RE_l , the difference was attributed to RE in tissue gain (**RE_g**). Heat energy associated with RE_g (**HE_g**) and ME used for tissue gain (**ME_g**) were based on an assumed efficiency of dietary ME use for tissue gain of 75% (AFRC, 1998). The amount of HE associated with use of dietary ME for lactation (**HE_{ld}**) was estimated as the difference between total HE and the sum of ME_m , HE_{lt} , and HE_g . The amount of dietary ME used for lactation (**ME_{ld}**) was the sum of RE_{ld} and HE_{ld} . The efficiency of use of ME_{ld} (k_{ld} , in %) was calculated as RE_{ld} divided by ME_{ld} . Also, an overall efficiency of use of ME (k_l) was estimated as the sum of fasting HE and RE_{ld} divided by MEI. This k_l and RE were the only calculations involving MEI. Because HE_{ld} and, thus, ME_{ld} were estimated based on HE rather than MEI, the sum of ME_{ld} , ME_m , and ME_g may not be identical to MEI.

Statistical Analysis

Data of lactating and nonlactating does were analyzed separately. Some data were omitted from statistical analyses. One nonlactating animal (60%C in late lactation) had relatively low feed intake during the period of measurement of intake, digestibility, and HE. Likewise, several lactating animals had low intake during a measurement period (e.g., 70% or less than consumed at earlier times). Moreover, there was an undetected problem in one of the 4 calorimetry measurement systems in late lactation. Ultimately, the number of observations was 11 in early and mid lactation for each diet and 8 and 7 in late lactation for the 60%C and 20%C diets, respectively.

Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). The initial model consisted of fixed effects of diet, the repeated measure

Table 2. Body weight, intake, and digestion for nonlactating Alpine does consuming 60 or 20% concentrate diets¹ at times corresponding to early, middle, and late stages of lactation of lactating does

Item	Diet	Stage of lactation			SEM	Diet		SEM
		Early	Middle	Late		60	20	
BW, kg	60	48.0	48.5	49.6	2.34			
	20	51.2	50.7	49.0				
Intake								
DM, g/d	60	799	799	788	29.3	796 ^b	874 ^a	17.4
	20	900	850	871				
OM, g/d	60	739	727	713	26.7	727 ^b	796 ^a	15.9
	20	826	758	804				
N, g/d	60	26.0	25.2	23.3	0.88			
	20	25.2	25.5	24.0				
NDF, g/d	60	249	252	261	11.4	254 ^b	386 ^a	6.8
	20	388	363	408				
Gross energy, MJ/d	60	15.3	15.2	14.9	0.56	15.2 ^b	16.6 ^a	0.33
	20	17.3	16.0	16.5				
Digestion, %								
DM	60	71.5 ^a	72.1 ^a	71.6 ^a	1.12			
	20	62.1 ^b	58.1 ^c	55.2 ^c				
OM	60	73.6 ^a	74.3 ^a	74.4 ^a	1.11			
	20	64.6 ^b	60.0 ^c	59.7 ^c				
N	60	77.3	76.6	75.8	1.16	76.7 ^a	68.8 ^b	0.66
	20	71.8	68.8	65.8				
NDF	60	44.0	48.6	49.8	2.21	47.7 ^a	42.1 ^b	1.25
	20	43.4	40.1	42.9				
	Mean	43.7	44.4	46.4				
Gross energy	60	71.5 ^a	72.2 ^a	73.8 ^a	1.55			
	20	63.7 ^b	58.2 ^c	56.1 ^c				

^{a-c}Means within diet, stage of lactation, or diet × stage of lactation groupings with different superscripts differ ($P < 0.05$).

¹Diets: 60 = 60% concentrate; 20 = 20% concentrate.

of stage of lactation, the dietary treatment × stage of lactation interaction, parity, and interactions involving parity, as well as the random effect of animal within dietary treatment. Neither effects of parity nor interactions involving parity were significant and, thus, were dropped from the model. Means were separated by least significant difference with a protected F -test ($P < 0.05$). Interaction means are presented in tables for all variables. Main effect means appear in tables when the interaction between dietary treatment and stage of lactation was nonsignificant and when the main effect was significant.

RESULTS

Diet Composition

Most notable differences in ingredient composition between the 20%C and 60%C diets were levels of alfalfa hay and ground corn (Table 1). Because alfalfa is a legume low in fiber compared with feedstuffs such as grass hay, the difference in dietary NDF concentration was only approximately 12 percentage units. Dietary CP concentrations were in excess of requirements (NRC, 2007), with each diet including feedstuffs relatively high in rumen undegraded intake protein (i.e.,

blood and fish meals). The 60%C diet included sodium bicarbonate to prevent low pH.

Nonlactating Animals

BW, Feed Intake, and Digestibility. Body weight was similar among stages of lactation and between diets (Table 2). Dry matter intake was 10% greater ($P < 0.05$) for the 20%C compared with the 60%C diet. Nitrogen intake was not affected by stage of lactation or diet. Intake of NDF was 52% greater for 20%C than for the 60%C diet ($P < 0.05$).

Digestibilities of DM, OM, and GE were greater for the 60%C than for the 20%C diet ($P < 0.05$) and were greater for the 20%C diet in early compared with mid and late lactation ($P < 0.05$; Table 2). Digestibilities of N were fairly similar to predictions based on relationships determined by Moore et al. (2004), although the difference between diets ($P < 0.05$) was slightly greater than expected, presumably because of the greater proportion of forage N in the 20%C compared with the 60%C diet. As expected, NDF digestibility was greater for the 60%C than for the 20%C diet in response to the greater proportion of legume in the 20%C than in the 60%C diet.

Table 3. Energy utilization by nonlactating Alpine does consuming 60 or 20% concentrate diets¹ at times corresponding to early, middle, and late stages of lactation of lactating does

Item ²	Diet	Stage of lactation			SEM	Diet		SEM
		Early	Middle	Late		60	20	
ME intake, MJ/d	60	9.43	9.85	9.43	0.458	9.57 ^a	8.54 ^b	0.27
	20	9.50	8.16	7.94				
ME intake, kJ/kg of BW ^{0.75}	60	519	528	508	18.7	518 ^a	448 ^b	10.9
	20	496	429	429				
Urine, MJ/d	60	0.88	0.43	0.68	0.067			
	20	0.98	0.54	0.72				
	Mean	0.93 ^a	0.49 ^c	0.70 ^b	0.048			
Methane, MJ/d	60	0.64	0.69	0.91	0.092			
	20	0.58	0.58	0.62				
Heat energy, kJ/kg of BW ^{0.75}								
Fed state	60	511	480	528	16.5	507 ^a	456 ^b	9.6
	20	468	434	467				
Fasted	60	341	324	336	14.7	332 ^a	304 ^b	8.5
	20	298	317	297				
k _m , %	60	67.6	70.6	60.4	2.38			
	20	65.9	72.2	60.9				
	Mean	66.7 ^{ab}	71.4 ^a	60.7 ^c	1.69			
ME _m , kJ/kg of BW ^{0.75}	60	508	459	544	25.3			
	20	452	440	498				
	Mean	479 ^{ab}	449 ^b	521 ^a	18.2			

^{a-c}Means within diet, stage of lactation, or diet × stage of lactation groupings with different superscripts differ ($P < 0.05$).

¹Diets: 60 = 60% concentrate; 20 = 20% concentrate.

²k_m = efficiency of ME utilization for maintenance; ME_m = ME used for maintenance.

It was planned that MEI would be similar between diets. Nonetheless, because of differences between actual and assumed dietary ME concentrations, MEI was approximately 1 MJ/d and 70 kJ/kg of BW^{0.75} greater for the 60%C than for the 20%C diet ($P < 0.05$; Table 3). Energy losses in urine and CH₄ were similar between diets, although urinary energy ranked ($P < 0.05$) as follows: early > late > mid lactation.

Heat, Energy, ME_m, and k_m. Heat energy when fed was similar to MEI and greater for the 60%C than for the 20%C diet ($P < 0.05$; Table 3). Likewise, fasting HE was greater for the 60%C than for the 20%C diet ($P < 0.05$), but the magnitude of difference ($P < 0.05$; 28 kJ/kg of BW^{0.75}) was slightly less than that in fed HE (49 kJ/kg of BW^{0.75}). The k_m was similar between diets but was lowest among stages of lactation in the late period ($P < 0.05$) and tended to be greater in mid than in early lactation ($P < 0.08$). Corresponding differences in ME_m were observed, although the value for the 60%C diet tended ($P < 0.08$) to be greater than for the 20%C diet. This tendency as well as similar k_m may have been influenced by greater MEI for the 60%C diet, resulting in MEI averaging 11 kJ/kg of BW^{0.75} greater than HE for the 60%C diet and 8 kJ/kg of BW^{0.75} lower for the 20%C diet. Hence, the k_m for the 60%C diet could have been slightly underestimated because of a small amount of tissue energy accretion with a lower efficiency than the true efficiency of dietary ME uti-

lization for maintenance. Using regression analysis to estimate ME_m of Freetly et al. (2006) by regressing RE (kJ/kg of BW^{0.75}) against MEI (kJ/kg of BW^{0.75}), the resultant equation from data of all lactating animals [RE = -319.8 + (0.6849 × MEI); R² = 0.90] yielded an ME_m of 467 kJ/kg of BW^{0.75}, which was fairly similar to the mean value determined in the present experiment with nonlactating does (i.e., 483 kJ/kg of BW^{0.75}).

Lactating Animals

BW and Milk Yield and Composition. Body weight was greater for 20%C animals than for 60%C animals ($P < 0.05$; Table 4). The allocation to diets was random in sets of 2 animals as kidding occurred. Hence, this difference in BW appears to have been a result of the dietary treatment assignment rather than a true dietary difference. Milk yield was greater in early and mid lactation than in late lactation and was greater for the 60%C compared with the 20%C diet ($P < 0.05$). As expected, milk fat concentration was greatest in late lactation ($P < 0.05$). However, the greater fat concentration for the 60%C compared with the 20%C diet ($P < 0.05$) was not anticipated. In part, this difference suggests that dietary inclusion of sodium bicarbonate prevented low ruminal pH and its potential negative effect on milk fat concentration. The lower effective fiber level in the legume hay used compared with other

Table 4. Body weight and milk yield and composition of Alpine does consuming 60 or 20% concentrate diets¹ in early, middle, and late stages of lactation

Item	Diet	Stage of lactation			SEM	Diet		SEM
		Early	Middle	Late		60	20	
BW, kg	60	50.4	49.1	51.7	1.73	50.0 ^b	53.3 ^c	1.00
	20	54.1	53.8	52.1				
Milk yield, kg/d	60	2.87	2.91	2.17	0.256	2.65 ^a	2.02 ^b	0.149
	20	2.62	2.28	1.16				
	Mean	2.74 ^a	2.60 ^a	1.66 ^b	0.181			
Milk composition								
DM, %	60	11.9	11.7	12.8	0.30	12.1 ^a	11.6 ^b	0.173
	20	11.3	10.9	12.6				
	Mean	11.6 ^b	11.3 ^b	12.7 ^a	0.21			
Fat, %	60	3.40	3.11	3.95	0.170	3.48 ^a	3.15 ^b	0.098
	20	3.04	2.73	3.67				
	Mean	3.22 ^b	2.92 ^b	3.81 ^a	0.120			
Protein, %	60	2.57	2.57	2.97	0.121			
	20	2.45	2.45	3.20				
	Mean	2.51 ^b	2.51 ^b	3.08 ^a	0.086			
Lactose, %	60	4.66	4.58	4.57	0.035	4.61 ^a	4.50 ^b	0.020
	20	4.57	4.48	4.56				
	Mean	4.61 ^a	4.53 ^{ab}	4.51 ^b	0.025			
TS, %	60	11.1	10.7	12.1	0.32			
	20	10.3	10.0	11.9				
	Mean	10.7 ^b	10.4 ^b	12.0 ^a	0.23			
Gross energy, kJ/g of DM	60	22.7	22.2	23.1	0.23	22.7 ^a	22.3 ^b	0.13
	20	22.5	21.6	22.8				
	Mean	22.6 ^a	21.9 ^b	23.0 ^a	0.16			

^{a-c}Means within diet × stage of lactation, diet, or stage of lactation grouping with different superscripts differ ($P < 0.05$).

¹Diets: 60 = 60% concentrate; 20 = 20% concentrate.

forages such as grass hay and cottonseed hulls also may have been involved in this difference. Similar to the level of fat, milk protein concentration was greatest ($P < 0.05$) in late lactation.

Feed Intake and Digestibility. Ad libitum intakes of DM, OM, and GE were similar among stages of lactation and between diets (Table 5). Intake of NDF was greater for the 20%C compared with the 60%C diet ($P < 0.05$). Digestibilities of DM, OM, and GE were slightly lower for lactating than for nonlactating animals. Also in accordance with values for nonlactating animals, these digestibilities were greater for the 60%C than for the 20%C diet and for the 20%C diet ranked ($P < 0.05$) as follows: early > mid > late lactation. The difference in N digestibility between diets for lactating animals was of similar magnitude to that for nonlactating animals. In accordance with greater DMI for lactating animals than for nonlactating animals (Moore et al., 2004), N digestibility was slightly less for animals when lactating. Intake of ME was greater for the 60%C than for the 20%C diet ($P < 0.05$; Table 6). Similar to nonlactating animals, urinary energy was greatest among stages in early lactation ($P < 0.05$). Methane emission was similar among stages of lactation and between diets.

Energy Utilization. Tissue energy change, loss or accretion, tended ($P < 0.07$) to vary with stage of lactation (Table 6). All diet × stage of lactation interaction treatment means were negative, in accordance with ADG from the beginning of periods to the start of calorimetry periods (i.e., −87, −14, and −5 g/d in early, mid, and late lactation, respectively; SEM = 11.2). Means for tissue energy change differed from those for ME_{lt} and ME_g because when no energy was mobilized from or accreted in tissue, the corresponding variable was set at 0.

Total HE was not affected by stage of lactation or diet (Table 6). In accordance with data for nonlactating animals, ME_m was lowest in mid lactation ($P < 0.05$) and tended ($P < 0.07$) to be greater in late lactation than in early lactation. Heat energy associated with use of dietary ME for lactation was greater ($P < 0.05$) in mid lactation than in early and late lactation. Conversely, RE_{ld} and ME_{ld} did not vary among stages of lactation. These findings were a function of the lower k_{ld} for mid lactation than for late lactation ($P < 0.05$) and a tendency ($P < 0.07$) for a lower value for mid lactation than for early lactation. Differences in k_{ld} among stages of lactation primarily resulted from relatively low ME_m in mid lactation, which again was estimated

Table 5. Intake and digestion by Alpine does consuming 60 or 20% concentrate diets¹ in early, middle, and late stages of lactation

Item	Diet	Stage of lactation			SEM	Diet		SEM
		Early	Middle	Late		60	20	
Intake								
DM, kg/d	60	1.46	1.69	1.64	0.112			
	20	1.74	1.74	1.69				
OM, kg/d	60	1.36	1.54	1.50	0.103			
	20	1.60	1.56	1.57				
N, g/d	60	45.4	50.0	44.0	3.52			
	20	47.3	49.9	46.5				
	Mean	45.9 ^{ab}	50.0 ^a	41.4 ^b	2.30			
NDF, kg/d	60	0.47	0.53	0.56	0.044	0.52 ^b	0.77 ^a	0.025
	20	0.76	0.77	0.77				
Gross energy, MJ/d	60	28.1	32.1	31.2	2.12			
	20	33.5	32.7	32.3				
Digestion, %								
DM	60	69.0 ^{ab}	70.6 ^a	67.4 ^a	0.90			
	20	59.5 ^c	56.8 ^d	53.1 ^e				
OM	60	70.8 ^{ab}	73.0 ^a	69.0 ^b	0.87			
	20	61.8 ^c	59.1 ^d	56.3 ^e				
N	60	74.4	72.7	69.2	1.10	72.1 ^a	64.9 ^b	0.64
	20	68.6	65.2	60.8				
	Mean	71.5 ^a	69.0 ^b	65.0 ^c	0.78			
NDF	60	37.2	41.9	39.4	2.36			
	20	38.1	36.3	34.8				
Gross energy	60	69.4 ^a	69.8 ^a	67.7 ^a	1.05			
	20	59.8 ^b	56.7 ^c	51.7 ^d				

^{a-e}Means within diet × stage of lactation, diet, or stage of lactation grouping with different superscripts differ ($P < 0.05$).

¹Diets: 60 = 60% concentrate; 20 = 20% concentrate.

from data of nonlactating animals. In this regard, when the efficiency of energy use for ME_m and lactation were considered together (i.e., k_l), efficiency of energy utilization was similar among stages of lactation.

Heat energy associated with use of mobilized tissue energy for lactation was greater in early lactation than in mid ($P < 0.08$) and late ($P < 0.05$) lactation (Table 6). Similar results were noted for RE_{lt} and ME_{lt} . Neither HE_g , RE_g , nor ME_g was influenced by stage of lactation or diet. Although treatment means indicate that tissue was mobilized for milk production throughout lactation, again it is relevant to note that when no mobilization occurred, HE_{lt} , RE_{lt} , and ME_{lt} were set at 0, with the same consideration for estimation of HE_g , RE_g , and ME_g when no tissue energy was accreted. In accordance, no treatment means for the latter variables differed from 0 ($P > 0.10$).

Total RE and RE_l were greater for the 60%C than for the 20%C diet ($P < 0.05$) because of differences ($P < 0.05$) of similar magnitude in RE_l and RE_{ld} and not involving RE_{lt} or RE_g (Table 6). Dietary ME used for lactation also tended to be greater ($P < 0.06$) for the 60%C than for the 20%C diet. The primary reason for the dietary difference in RE_l , RE_{ld} , and ME_{ld} was the greater k_{ld} for the 60%C diet ($P < 0.05$). The greater magnitude of difference between diets in k_{ld} compared with k_l ($P < 0.05$) was a consequence of the similar k_m

between diets determined with nonlactating animals. With the approach of Freely et al. (2006) for beef cows of regressing RE_{ld} against ME_{ld} to estimate k_{ld} , use of all lactating doe data resulted in a value of 58.1% [$RE_{ld} = 0.8766 + (0.5808 \times ME_{ld})$; $R^2 = 0.83$], which was quite similar to the average of treatment means of the present experiment.

DISCUSSION

Digestibility

Because DMI was similar among stages of lactation, greater DM, OM, and GE digestibilities for nonlactating animals fed the 20%C diet in early lactation compared with in mid and late lactation would not appear related to ruminal residence time of digesta. However, it is reasonable to assume that more rapid passage of digesta from the reticulorumen in lactating animals compared with nonlactating animals, because of greater DMI by lactating animals, contributed to lower digestibilities. Differences in digestibilities between nonlactating and lactating animals were of a magnitude similar to that suggested by AFRC (1998) to account for effects of level of feed intake (i.e., 1.8% decrease per unit increase in feeding level above ME_m). The dietary fiber level did not seem responsible for differences in digestion between stages of lactation with the 20%C diet, as the dietary

NDF concentration averaged 40.1, 40.3, and 44.1% in early, mid, and late lactation, respectively.

Energy Use for Maintenance

The k_m predicted based on the formula of AFRC (1998), $[(0.35 \times \text{diet metabolizability}) + 0.503] \times 100$, was 73.1

and 66.9% for the 60%C and 20%C diets, respectively. Hence, k_m in the present experiment was considerably less for the 60%C diet than predicted by the AFRC (1998) equation but was similar for the 20%C diet. The AFRC (1998) equation was suggested for all goats rather than specifically for dairy goats. In this regard, based on reports of Luo et al. (2004) and Sahlu et al. (2004), the

Table 6. Energy utilization by Alpine does consuming 60 or 20% concentrate diets¹ in early, middle, and late stages of lactation

Item ²	Diet	Stage of lactation			SEM	Diet		SEM
		Early	Middle	Late		60	20	
ME intake, MJ/d	60	17.3	19.9	18.5	1.27	18.6 ^a	16.3 ^b	0.74
	20	17.9	16.5	14.6				
Urine, MJ/d	60	1.17	0.75	0.83	0.075			
	20	1.14	0.79	0.90				
	Mean	1.16 ^a	0.77 ^b	0.86 ^b	0.053			
Methane, MJ/d	60	0.95	1.58	1.76	0.202			
	20	1.11	1.26	1.30				
	Mean	1.03 ^b	1.42 ^a	1.39 ^a	0.143			
Tissue accretion (+) or loss (-), MJ/d	60	-3.03	-1.04	-0.93	0.696			
	20	-1.80	-1.53	-0.59				
Heat energy expenditure (HE), MJ/d								
Total	60	12.69	13.64	13.12	0.582			
	20	13.10	12.62	11.83				
ME _m	60	9.79	8.50	10.07	0.227			
	20	9.00	8.73	9.61				
	Mean	9.40 ^{ab}	8.62 ^c	9.84 ^a	0.161			
Diet for lactation (HE _{ld})	60	2.32	4.73	2.70	0.559			
	20	3.57	3.49	1.91				
	Mean	2.94 ^b	4.11 ^a	2.30 ^b	0.396			
Tissue for lactation (HE _{lt})	60	0.58	0.27	0.24	0.111			
	20	0.41	0.33	0.19				
	Mean	0.50 ^a	0.30 ^{ab}	0.21 ^b	0.079			
Gain (HE _g)	60	0.00	0.13	0.11	0.071			
	20	0.12	0.07	0.13				
Recovered energy (RE), MJ/d								
Total	60	4.65	6.29	5.38	0.860	5.44 ^a	3.78 ^b	0.499
	20	4.76	3.84	2.73				
Total in milk (RE _l)	60	7.69	7.32	6.31	0.635	7.11 ^a	5.09 ^b	0.368
	20	6.56	5.37	3.32				
	Mean	7.12 ^a	6.35 ^{ab}	4.82 ^c	0.449			
Milk from the diet (RE _{ld})	60	4.66	5.89	5.04	0.765	5.20 ^a	3.45 ^b	0.444
	20	4.39	3.63	2.34				
Milk from tissue (RE _{lt})	60	3.03	1.44	1.27	0.582			
	20	2.17	1.74	0.98				
	Mean	2.60 ^a	1.59 ^{ab}	1.13 ^b	0.411			
Tissue (RE _g)	60	0.00	0.40	0.34	0.214			
	20	0.37	0.21	0.39				
ME used in lactation, MJ/d								
Dietary (ME _{ld})	60	6.98	10.62	7.74	1.194			
	20	7.96	7.12	4.25				
Tissue (ME _{lt})	60	3.61	1.71	1.51	0.693			
	20	2.58	2.07	1.17				
	Mean	3.10 ^a	1.89 ^{ab}	1.34 ^b	0.490			
ME for tissue gain (ME _g)	60	0.00	0.53	0.45	0.285			
	20	0.49	0.29	0.52				
k _{ld} , %	60	66.1	56.8	66.6	5.21			
	20	53.0	47.0	64.3				
	Mean	59.5 ^{ab}	51.9 ^b	65.4 ^a	3.68			
k _l , %	60	67.5	62.7	62.6	1.78	64.3 ^a	60.9 ^b	1.03
	20	60.8	62.1	59.9				

^{a-c}Means within diet $\times$ stage of lactation, diet, or stage of lactation grouping with different superscripts differ ($P < 0.05$).

¹Diets: 60 = 60% concentrate; 20 = 20% concentrate.

²Some abbreviations are given in parentheses to aid in viewing tables in conjunction with the text. ME_m = ME used for maintenance; k_{ld} = efficiency of utilization of dietary energy for lactation; k_l = efficiency of use of dietary energy for maintenance and lactation.

ME_m requirement of dairy goats is greater than that of meat and indigenous or local goats.

The lack of difference in k_m between the 60%C and 20%C diets in and of itself is not in accordance with the approach of Nsahlai et al. (2004) in use of the aforementioned AFRC (1998) equation. However, as noted earlier, k_m for the 60%C diet might have been slightly underestimated because of tissue accretion, and fasting HE could have been increased for the same reason as well. Furthermore, with the method of Nsahlai et al. (2004) in determining the ME requirement for lactation per unit of milk energy regardless of diet, inclusion of an effect of diet quality on k_m seems warranted. Also, there may be compensating factors to consider. For example, k_m was similar between diets and k_{ld} was greater for the 60%C than for the 20%C diet in the present experiment and, conversely, Nsahlai et al. (2004) varied k_m with diet metabolizability and estimated a single k_{ld} for all diets.

The magnitude of difference between diets in fed HE of nonlactating animals is in agreement with that in fasted HE and similar k_m . Thus, factors such as potential dietary differences in the profile of nutrients absorbed were of little or no consequence. Metabolic machinery or support tissues (e.g., gastrointestinal tract and liver) to be maintained with the 60%C diet presumably were greater than for the 20%C diet as a consequence of greater MEI for the 60%C diet (Johnson et al., 1990). Energy metabolized to satisfy this extra demand for the 60%C diet incurred the same inefficiency or loss of heat above and relative to fasting HE as did the lesser amount of metabolic machinery being maintained with the 20%C diet because of lower MEI. However, this is not necessarily directly applicable to lactating animals with higher MEI and all coordinated physiological processes involved in milk secretion.

The ME_m for mature dairy goats (501 kJ/kg of BW^{0.75}) assumed by Nsahlai et al. (2004) to estimate the requirement for milk production, recommended by Sahlu et al. (2004) and NRC (2007), was intermediate to that determined in this experiment with nonlactating animals in early and late lactation periods. The value for mid lactation was, however, considerably lower. It cannot be conclusively discerned why k_m was lower and ME_m was greater when determined in nonlactating animals in late lactation compared with mid lactation, with intermediate values during early lactation. Environmental conditions were conceivably involved given that the warmest period was in mid lactation. However, findings of Patra et al. (2009) with Boer and Spanish yearling doelings housed in the same facility do not support marked effects on ME_m of seasonal differences in temperature and humidity. Nonetheless, with this experimental design, values for nonlactating animals

were applied to lactating animals assuming similar differences among the 3 measurement times corresponding to early, mid, and late stages of lactation of lactating animals. Such an approach has limitations in that potential interactions between physiological conditions of nonlactating and lactating animals and factors such as environmental conditions and fluctuations in dietary characteristics are not considered.

Energy Use for Lactation

The lower k_{ld} in mid lactation than in early and late stages of lactation was a function of lower ME_m and greater k_m estimated with nonlactating animals. Similar k_l among stages of lactation for lactating animals indicates that the overall efficiency of energy metabolism of dietary ME for maintenance and lactation did not differ among stages of lactation. Because maintenance energy requirements vary with physiological conditions as influenced by level of MEI and perhaps the origin of energy used for milk production (i.e., dietary and mobilized tissue) as well as use of energy for tissue energy accretion, given the method of estimating ME_m in this experiment, k_l may be preferable to evaluate efficiency of metabolism of dietary ME or, alternatively, assessment should consider both k_{ld} and ME_m. Such an approach, as used by many systems for dairy cattle (e.g., NRC, 2001), has the attribute of avoiding the issue of whether level of intake and physiological state effects on HE should be categorized as maintenance or production functions (Williams and Jenkins, 2003).

On the basis of k_{ld} only, findings of the present experiment disagree with little or no effect of stage of lactation on the energy requirement for milk energy yield determined by Nsahlai et al. (2004). But, in regards to k_l , results of this experiment are similar to findings of Nsahlai et al. (2004). In addition, with studies such as Nsahlai et al. (2004) relying on databases of treatment mean observations constructed from the literature, sometimes with less than desired clarity in the description of procedures and with experimental periods not always restricted to specific stages of lactation, evaluation of effects of factors like stage of lactation can be challenging.

The AFRC (1998) equation to predict k_{ld} , $[(0.35 \times \text{diet metabolizability}) + 0.420] \times 100$, yielded estimates of 64.8 and 60.6% for the 60%C and 20%C diets, respectively. In contrast to differences in k_m between observations of the present study and AFRC (1998) predictions, for k_{ld} values were similar with the 60%C diet but greater for the AFRC (1998) prediction with the 20%C diet.

Greater MEI for the 60%C diet coupled with the tendency for greater ME_m based on nonlactating animal

data compared with the 20%C diet may have contributed to greater k_{ld} and k_l for the 60%C than for the 20%C diet. That is, with a relatively high ME_m the proportion of MEI contributing to milk energy yield was correspondingly low. These results suggest that the magnitude of the effect of the difference between diets in MEI involved a threshold effect of energy availability on the cost of maintenance of metabolic machinery or support tissues involved in milk secretion. In other words, energy required for maintenance of metabolic machinery necessary for milk secretion decreased with increasing energy availability relevant to the 60%C versus the 20%C diet or reached a certain point above which no increase or relatively small change occurred. In addition, although the difference between diets in k_{ld} was greater than that in k_l , because k_m was determined with nonlactating animals at a level of intake near maintenance and k_{ld} was estimated with lactating animals, it is possible that the diet effect on k_{ld} was at least partially attributable to effects on energy use per unit of energy absorption by metabolically active tissues such as the gastrointestinal tract, with less effect of diets moderate to high in concentrate feedstuffs compared with ones higher in level of forage (Goetsch, 1998). But, it is also possible that differences between the 60%C and 20%C diets in the profile of absorbed nutrients affected k_{ld} (NRC, 2001).

Treatment means for HE_g , RE_g , and ME_g were low and not different from 0. Treatment means for HE_{lt} , RE_{lt} , and ME_{lt} were slightly greater than those for tissue energy accretion, in agreement with ADG means that were negative for each stage of lactation. Hence, planes of nutrition throughout the lactation period did not facilitate appreciable replenishment of body energy stores, in contrast to findings of Ngwa et al. (2009), particularly in late lactation. Therefore, under these conditions a relatively high plane of nutrition after measurements in the late stage of lactation and during the subsequent dry period would be needed to attain physiological conditions conducive to optimal performance during rebreeding, gestation, and the next lactation.

Prediction of Lactation Performance

Even though limitations of methods used by Nsahla et al. (2004) to derive energy requirements of lactating dairy goats recommended by Sahlu et al. (2004) and NRC (2007) have been addressed earlier, predictions based on those expressions of results in the present experiment were reasonably accurate given the nature of measurements taken. One of the most important estimates required for accurate prediction of milk yield at a certain level of DMI or of DMI required to achieve a specific milk yield is BW change or ADG. The degree

to which ADG truly reflects tissue energy mobilization for use in milk secretion or energy accretion is affected by constancy of digesta mass in the digestive tract. The potential magnitude of effect of ADG on such predictions can be assessed by comparing actual milk yield with that predicted at 0 ADG. With use of the Web-based goat nutrient requirement calculation system of Langston University (www2.luresext.edu), which applies NRC (2007) recommendations, predicted milk yield with 0 ADG was 1.67, 2.38, 1.95, 1.53, 1.62, and 1.45 kg/d for the 60%C diet in early, mid, and late lactation and for the 20%C diet in early, mid, and late lactation, respectively. Observed values were considerably greater. Estimates of ADG were -99, -21, -7, -76, -6, and -2 g/d for the 60%C diet in early, mid, and late lactation and for the 20%C diet in early, mid, and late lactation, respectively (SEM = 15.8). When the ADG means were considered, predicted milk yield was 3.17, 2.70, 2.03, 2.67, 1.72, and 1.38 kg/d for the 60%C diet in early, mid, and late lactation and for the 20%C diet in early, mid, and late lactation, respectively. These values were similar to observations, except perhaps for the 20%C diet in mid lactation (difference of 0.56 kg/d); differences for other diet $\times$ stage of lactation interaction means ranged from -0.30 to 0.21 kg/d. Similarly, based on main effect means for dietary treatments, predicted milk yield was 2.65 and 1.90 kg/d for the 60%C and 20%C diets, respectively, with the former value the same as observed and the latter value just 0.22 kg/d less. Hence, it can be concluded that NRC (2007) energy requirement recommendations resulted in reasonably accurate predictions of findings of this experiment.

CONCLUSIONS

The k_m determined with nonlactating animals differed among periods of time when lactating animals were in early, mid, and late lactation. This may have contributed to differences among stages of lactation in k_{ld} of lactating animals. However, k_l was not affected by stage of lactation. The k_m for the 60%C and 20%C diets determined in nonlactating animals was similar, although both k_{ld} and k_l were greater in lactating animals for the 60%C than for the 20%C diet. These findings demonstrate limitations of approaches to study efficiency of energy use and requirements of lactating dairy goats with maintenance needs estimated from corresponding nonlactating animals. Predictions of milk yield from energy requirement recommendations of NRC (2007) were reasonably accurate.

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REFERENCES

- AFRC. 1993. Energy and protein requirements of ruminants. Pages 5–55 in *An Advisory Manual Prepared by the AFRC Technical Committee on Responses to Nutrients*. CAB International, Wallingford, UK.
- AFRC. 1998. *The Nutrition of Goats*. CAB International, New York, NY.
- AOAC. 1990. *Official Methods of Analysis*. 15th ed. Association of Official Analytical Chemists, Arlington, VA.
- Brouwer, E. 1965. Report of sub-committee on constants and factors. Pages 441–443 in *Energy Metabolism: Proc. 3rd Symp.* K. L. Blaxter, ed. EAAP Publ. No. 11. Academic Press, London, UK.
- Freetly, H. C., J. A. Nienaber, and T. Brown-Brandl. 2006. Partitioning of energy during lactation of primiparous beef cows. *J. Anim. Sci.* 84:2157–2162.
- Goetsch, A. L. 1998. Splanchnic tissue energy use in ruminants that consume forage ad libitum. *J. Anim. Sci.* 76:2737–2746.
- Johnson, D. E., K. A. Johnson, and R. L. Baldwin. 1990. Changes in liver and gastrointestinal tract energy demands in response to physiological workload in ruminants. *J. Nutr.* 120:649–655.
- Luo, J., A. L. Goetsch, T. Sahlu, I. V. Nsahlai, Z. B. Johnson, J. E. Moore, M. L. Galyean, F. N. Owens, and C. L. Ferrell. 2004. Prediction of metabolizable energy requirements for maintenance and gain of preweaning, growing, and mature goats. *Small Rumin. Res.* 53:309–328.
- Moore, J. E., A. L. Goetsch, J. Luo, F. N. Owens, M. L. Galyean, Z. B. Johnson, T. Sahlu, and C. L. Ferrell. 2004. Prediction of fecal crude protein excretion of goats. *Small Rumin. Res.* 53:275–292.
- Ngwa, A. T., L. J. Dawson, R. Puchala, G. D. Detweiler, R. C. Merkel, Z. Wang, K. Tesfai, T. Sahlu, C. L. Ferrell, and A. L. Goetsch. 2009. Effects of stage of lactation and dietary concentrate level on body composition of Alpine dairy goats. *J. Dairy Sci.* 92:3374–3385.
- NRC. 1981. *Nutrient Requirements of Goats: Angora, Dairy and Meat Goats in Temperate and Tropical Countries*. National Academy Press, Washington, DC.
- NRC. 2001. *Nutrient Requirements of Dairy Cattle*. 7th rev. ed. National Academy Press, Washington, DC.
- NRC. 2007. *Nutrient Requirements of Small Ruminants. Sheep, Goats, Cervids, and New World Camelids*. National Academy Press, Washington, DC.
- Nsahlai, I. V., A. L. Goetsch, J. Luo, J. E. Moore, Z. B. Johnson, T. Sahlu, C. L. Ferrell, M. L. Galyean, and F. N. Owens. 2004. Energy requirements for lactation of goats. *Small Rumin. Res.* 53:253–274.
- Patra, A. K., R. Puchala, G. Animut, T. A. Gipson, T. Sahlu, and A. L. Goetsch. 2009. Effects of acclimatization on energy expenditure by meat goats. *Small Rumin. Res.* 81:42–54.
- Sahlu, T., A. L. Goetsch, J. Luo, I. V. Nsahlai, J. E. Moore, M. L. Galyean, F. N. Owens, C. L. Ferrell, and Z. B. Johnson. 2004. Energy and protein requirements of goats: Developed equations, other considerations and future research to improve them. *Small Rumin. Res.* 53:191–220.
- Tovar-Luna, I., A. L. Goetsch, R. Puchala, T. Sahlu, G. E. Carstens, H. C. Freetly, and Z. B. Johnson. 2007. Effects of moderate feed restriction on energy expenditure by 2-year-old crossbred Boer goats. *Small Rumin. Res.* 72:25–32.
- Williams, C. B., and T. G. Jenkins. 2003. A dynamic model of metabolizable energy utilization in growing and mature cattle. I. Metabolizable energy utilization for maintenance and support metabolism. *J. Anim. Sci.* 81:1371–1381.