Effects of stage of lactation and level of feed intake on energy utilization by Alpine dairy goats

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ABSTRACT

Thirty-six lactating Alpine does were used to determine effects of stage of lactation and level of feed intake on energy utilization. Twelve does were assigned to measurement periods in early, mid, and late lactation (wk 5, 13, and 27, respectively). For 6 does of each group, after ad libitum consumption of a 60% concentrate diet, feed intake was restricted to near the metabolizable energy (ME) requirement for maintenance (ME_m) for 8 d followed by fasting for 4 d. For other does, fasting immediately followed ad libitum consumption. Intake of ME was similar among stages of lactation with ad libitum intake (22.1, 22.1, and 19.8 kJ/d in early, mid, and late lactation, respectively). The efficiency of ME use for maintenance determined with does fed near ME_m averaged 81%. Fasting heat energy was greater for ad libitum consumption than for near ME_m consumption [368 vs. 326 kJ/kg of body weight ($BW^{0.75}$)] and was numerically lowest among stages in late lactation with near ME_m intake (334, 350, and 295 kJ/kg of $BW^{0.75}$ in early, mid, and late lactation, respectively) and ad libitum consumption (386, 384, and 333 kJ/kg of $BW^{0.75}$ in early, mid, and late lactation, respectively). The efficiency of use of dietary ME for lactation was greater for consumption near ME_m than for consumption ad libitum (67.9 vs. 58.6%) and with ad libitum consumption tended to decrease with advancing stage of lactation (63.9, 57.3, and 54.5% for early, mid, and late lactation, respectively). Estimated ME_m was greater for ad libitum intake than for near ME_m intake and was lowest during late lactation (429, 432, and 358 kJ/kg of $BW^{0.75}$ for near ME_m intake and 494, 471, and 399 kJ/kg of $BW^{0.75}$ for ad libitum intake in early, mid, and late lactation, respectively). However, because of increasing BW as the experiment progressed, ME_m (MJ/d) was similar among stages of lactation with both levels of intake. The efficiency of ME use for

maintenance and lactation was similar among stages of lactation and greater with near ME_m intake than ad libitum intake (77.1 vs. 67.7%). In conclusion, the ME_m requirement (kJ/kg of $BW^{0.75}$) of does in late lactation was less than in early and mid lactation. A marked effect of restricted feed intake subsequent to ad libitum consumption was observed on estimates of efficiency of energy use for maintenance and lactation was observed compared with use of nonlactating animals. Level of feed intake can have substantial effect on estimates of energy utilization by lactating dairy goats.

Key words: dairy goat, lactation, energy

INTRODUCTION

Different approaches have been used to study energy utilization and requirements of lactating dairy goats. Nsahlai et al. (2004) used various assumptions and regression of dietary ME used for lactation against FCM or milk energy yield with a database of treatment mean observations from the literature. The study of Tovar-Luna et al. (2010) employed both lactating and nonlactating goats. Heat energy (**HE**) of nonlactating goats when fed near the ME requirement for maintenance (ME_m) and while fasting was used to estimate the efficiency of energy utilization for maintenance (k_m) and the ME_m requirement. Mean values for different diets and stages of lactation were then applied to corresponding lactating goats for estimating the ME requirement and efficiency of dietary ME use for lactation (k_{ld}). A consideration for this approach is that energy used by support tissues of nonlactating animals, such as the gastrointestinal tract and liver, should be less than that of the lactating counterparts (Williams and Jenkins, 2003). Hence, energy use by support tissue metabolism is considered part of the maintenance requirement rather than that for production or lactation (Williams and Jenkins, 2003). The ME_m requirement of lactating animals would be underestimated, dietary energy used in lactation overestimated, and k_{ld} underestimated. Furthermore, variability among animals in ME_m is ignored with this methodology. Therefore, the

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Table 1. Composition of the diet consumed by lactating Alpine does

Item	% DM
Ingredient	
Cottonseed hulls	20.42
Ground alfalfa hay	20.19
Ground corn	32.85
Soybean meal	11.31
Blood meal	1.04
Fish meal	3.57
Molasses	2.52
Fat ¹	3.33
Dicalcium phosphate	1.00
Limestone	0.91
Ammonium sulfate	0.28
Sodium bicarbonate	1.12
Vitamin premix ¹	0.56
Trace mineralized salt ²	0.56
Magnesium oxide	0.34
Chemical composition	
Ash	7.9
NDF	33.4
ADF	25.3
Acid detergent lignin	7.6
CP	18.3

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

²Contained 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.

objectives of this experiment were to determine effects of stage of lactation on energy utilization by lactating Alpine goats by sequential use of different levels of intake: ad libitum, near ME_m, and fasting.

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-six multiparous lactating Alpine does averaging 4.5 yr of age (SEM = 0.26) were used. As kidding occurred, at 3 d after parturition, does were randomly assigned in sets of 6 to treatments of early, middle, and late stages of lactation and 2 feed intake regimens. All does consumed a 60% concentrate diet (Table 1), which had the same ingredient composition as the 60% concentrate diet in the study of Tovar-Luna et al. (2010). 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 an enclosed facility with individual feeding by Calan gates (American Calan Inc., Northwood, NH) and continual access to water. Intake was

ad libitum at most times, with diets offered at 110% of consumption on the preceding few days at 0800 and 1500 h (70 and 30% of daily allocation, respectively).

In wk 4, 12, and 26 of lactation, 3 sets of 4 does assigned to each stage of lactation were moved sequentially to metabolism crates equipped with head boxes for adaptation to conditions similar to those used later for calorimetry measurements. After 1 wk of adaptation, total feces and urine collections and calorimetry measures were taken over a 7-d period in wk 5, 13, and 27 (i.e., early, middle, and late stages of lactation, respectively). Thereafter, 6 does were fasted for 4 d, with calorimetry measures on d 3 and 4. The other 6 does were fed at ME_m for 8 d based on AFRC (1998). Assumed dietary ME concentrations were based on feedstuff composition listings of NRC (1981). Feces and urine were collected on the last 4 d, with calorimetry measures on the final 2 d. A 4-d fasting period was then imposed, with calorimetry measures on the last 2 d. Therefore, 6 observations were made for which fasting immediately followed ad libitum intake in each stage of lactation. Likewise, 6 observations were made with intake near maintenance followed by fasting. An alternative was to have 12 observations per stage of lactation with ad libitum intake, which would have included the animals fed near ME_m before fasting. However, as evident later in the description of calculations, this would have prevented estimation of ME_m of animals consuming ad libitum and directly fasted thereafter based on fasting HE of these specific animals, with estimation alternatively based on the mean ME_m of the other 6 animals at each stage of lactation that were fed near ME_m before fasting. Thus, for both methods of estimation, ME_m was based on actual fasting HE of individual does, albeit for does consuming ad libitum then fasted. The average k_m of animals fasting immediately after being fed near ME_m was employed. For both sets of animals with fasting HE determined after intake ad libitum and maintenance, ME_m (MJ/d) was based on average BW during the period of determining intake, digestibility, and HE preceding fasting rather than average BW during the fasting period.

Nutrient Balance and Milk

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 (15%) 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, with milk yield recorded in the 3 stages of lactation. Milk samples were collected at both times on d 1, 4, and 7 of the collection periods in the 3 stages of lactation with ad libitum and maintenance levels of intake. During 4-d fasting periods, milk was sampled daily. 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). The instrument 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

For calorimetry measures, does were moved into a room with 4 metabolic 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 ($20\text{--}23^{\circ}\text{C}$) 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.

Calculations

Calculations were similar to those of Tovar-Luna et al. (2010). Intake of ME (**MEI**) was calculated from GE intake and energy losses in feces, urine, and CH_4 . Heat energy 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. 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.

With ad libitum intake, 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 metabolized tissue energy for milk synthesis (**HE_{lt}**) were determined from 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 in 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). Dietary ME used for **ME_m** was determined from fasting HE corrected for **HE_{lt}** divided by k_m as a fraction. As noted earlier, k_m (%) assumed was derived from the average of individual animal values at the same stage of lactation when fed near maintenance, determined as 100 minus the slope of the regression of HE, corrected for **HE_{lt}**, against MEI when fed near maintenance and fasted. The amount of HE associated with use of dietary ME for lactation was estimated as the difference between HE and the sum of **ME_m**, **HE_{lt}**, and **HE_g**. 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}**; expressed as %) was calculated as **RE_{ld}** divided by **ME_{ld}**. Also, an overall efficiency of use of ME for maintenance and lactation (**k_l**; expressed as %) 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 when intake was ad libitum and near maintenance were analyzed separately. Data were analyzed using the GLM procedure of SAS (SAS Institute Inc., Cary, NC) with a model consisting of stage of lactation. Means were separated by least significant difference with a protected *F*-test ($P < 0.05$). In addition, for some of the energy utilization variables, data for both levels of intake were analyzed together with the GLM procedure, with a model including level of intake, stage

Table 2. Body weight and milk yield and composition for Alpine does when consuming a 60% concentrate diet ad libitum or near the requirement for maintenance in early, middle, and late stages of lactation

Item	Ad libitum intake				Intake near maintenance			
	Early	Middle	Late	SEM	Early	Middle	Late	SEM
BW, kg	47.1 ^b	49.2 ^b	55.2 ^a	1.87	44.9	48.2	54.1	2.70
Milk yield, kg/d	3.61 ^a	3.01 ^b	1.61 ^c	0.166	1.59 ^a	1.47 ^a	0.81 ^b	0.132
Milk composition								
DM, %	11.3 ^b	11.3 ^b	13.3 ^a	0.26	11.7 ^b	11.4 ^b	15.3 ^a	0.566
Fat, %	2.77 ^c	3.30 ^b	3.92 ^a	0.131	3.21 ^b	3.49 ^b	5.28 ^a	0.317
Protein, %	2.35 ^b	2.46 ^b	4.04 ^a	0.116	2.33 ^b	2.74 ^b	4.30 ^a	0.197
Lactose, %	4.66 ^a	4.59 ^a	3.89 ^b	0.105	4.61	4.51	4.57	0.041
TS, %	10.4 ^b	10.8 ^b	12.6 ^a	0.24	10.6 ^b	11.2 ^b	14.9 ^a	0.38
Gross energy, ¹ kJ/g of DM	21.7 ^c	23.2 ^b	24.6 ^a	0.19	22.6 ^c	23.8 ^b	26.2 ^a	0.25

^{a-c}Means within level of intake grouping with different superscripts differ ($P < 0.05$).

of lactation, and the interaction between intake level and lactation stage.

RESULTS

BW and Milk Yield and Composition

Body weight of does consuming ad libitum was greater in late lactation than in early and mid lactation ($P < 0.05$; Table 2). The effect of stage of lactation on BW during feeding near the ME_m requirement tended ($P < 0.09$) to be significant, ranking early < mid < late lactation. Dry matter, protein, and TS concentrations in milk were greatest ($P < 0.05$) in late lactation for does both consuming ad libitum and near the ME_m requirement. Milk fat concentration for does consuming ad libitum ranked ($P < 0.05$) as follows: early < mid < late lactation. With consumption near ME_m the level of milk fat was greater ($P < 0.05$) in late lactation than in early and mid lactation. Milk lactose concentration for does consuming ad libitum was lowest in late lactation ($P < 0.05$) and was similar among stages of lactation

for does fed near ME_m. For both levels of intake, GE concentration in milk ranked ($P < 0.05$) as follows: early < mid < late lactation.

Intake and Digestion

Ad libitum intakes of DM, OM, N, NDF, and GE were greater in early and mid lactation than in late lactation ($P < 0.05$), whereas near ME_m intakes were similar among stages of lactation (Table 3). Intakes by animals fed near ME_m were similar among stages of lactation except for lowest NDF intake in early lactation ($P < 0.05$).

Digestibilities of DM and OM in does consuming ad libitum were lowest among stages ($P < 0.05$) in early lactation, and N digestion was greater ($P < 0.05$) in late than in early lactation ($P < 0.05$; Table 3). Digestibilities of NDF and GE ranked ($P < 0.05$) as follows: early < mid < late lactation. All digestibilities were greater for does with near ME_m intake compared with ad libitum intake, with the greatest magnitude of difference for NDF. No differences were found among

Table 3. Intake and digestion by Alpine does when consuming a 60% concentrate diet ad libitum or near the requirement for maintenance in early, middle, and late stages of lactation

Item	Ad libitum intake				Intake near maintenance			
	Early	Middle	Late	SEM	Early	Middle	Late	SEM
Intake								
DM, kg/d	1.96 ^a	1.98 ^a	1.61 ^b	0.063	0.77	0.84	0.87	0.030
OM, kg/d	1.83 ^a	1.86 ^a	1.50 ^b	0.058	0.70	0.78	0.80	0.028
N, g/d	52.6 ^a	50.2 ^a	43.1 ^b	2.18	23.4	22.6	25.7	0.089
NDF, kg/d	0.67 ^a	0.69 ^a	0.58 ^b	0.019	0.25 ^b	0.29 ^a	0.29 ^a	0.010
GE, ¹ MJ/d	36.4 ^a	37.3 ^a	29.8 ^b	1.16	14.2	15.7	15.9	0.56
Digestion, %								
DM	65.5 ^b	67.5 ^a	68.5 ^a	0.65	72.1	74.3	74.1	1.55
OM	67.0 ^b	69.0 ^{ab}	70.1 ^a	0.68	74.3	76.3	76.2	1.44
N	70.0 ^b	71.4 ^{ab}	72.8 ^a	0.69	78.4	77.2	78.8	1.27
NDF	33.0 ^c	39.0 ^b	46.5 ^a	1.31	48.2	56.6	56.4	2.71
Gross energy	65.6 ^c	67.8 ^b	70.8 ^a	0.68	73.4	75.0	77.4	1.45

^{a-c}Means within level of intake grouping with different superscripts differ ($P < 0.05$).

Table 4. Energy utilization by Alpine does consuming a 60% concentrate diet ad libitum or near the requirement for maintenance in early, middle, and late stages of lactation¹

Item ²	Ad libitum intake				Intake near maintenance			
	Early	Middle	Late	SEM	Early	Middle	Late	SEM
ME intake (MEI), MJ/d	22.14	22.11	19.81	0.857	9.81	10.38	10.77	0.479
Urine, MJ/d	0.81 ^a	0.57 ^b	0.87 ^a	0.069	0.39 ^b	0.41 ^b	0.56 ^a	0.035
Methane, MJ/d	0.94 ^b	1.01 ^b	2.12 ^a	0.262	0.24 ^b	0.95 ^a	0.98 ^a	0.069
Tissue accretion (+) or loss (–), MJ/d	–0.08	0.45	1.00	0.645	–3.07 ^b	–2.78 ^b	–0.99 ^a	0.495
Heat energy (HE), MJ/d unless noted								
Total	13.51	14.21	13.40	0.543	8.77	9.21	8.49	0.436
Fasting ³	6.70	6.94	6.80	0.468	5.78	6.41	5.88	0.408
Fasting, kJ/kg of BW ^{0.75}	386	384	333	17.9	334 ^{ab}	350 ^b	295 ^b	16.6
ME _m	8.58	8.51	8.14	0.578	7.46	7.92	7.13	0.482
Lactation from the diet (HE _{ld})	4.64	5.18	4.90	0.608	0.72	0.76	1.02	0.120
Use of tissue for lactation (HE _{lt}) ⁴	0.11	0.14	0.01	0.063	0.59 ^a	0.53 ^a	0.24 ^b	0.081
Gain (HE _g) ⁵	0.17	0.39	0.35	0.127	0	0	0.09	0.042
Recovered energy (RE), MJ/d								
Total	8.63 ^a	7.89 ^{ab}	6.40 ^b	0.588	1.04	1.17	2.28	0.382
Total in milk (RE _l)	8.72 ^a	7.44 ^a	5.40 ^b	0.588	4.12	3.95	3.27	0.400
Milk from the diet (RE _{ld})	8.22 ^a	6.83 ^b	5.35 ^c	0.390	1.53	1.62	2.20	0.280
Milk from tissue (RE _{lt})	0.50	0.61	0.05	0.278	2.58 ^a	2.34 ^a	1.07 ^b	0.358
Tissue (RE _g)	0.51	1.18	1.06	0.380	0	0	0.28	0.125
ME used in lactation, MJ/d								
Dietary (ME _{ld})	12.86	12.02	10.25	0.801	2.25	2.38	3.23	0.400
Tissue (ME _{lt})	0.70	0.86	0.07	0.394	3.66 ^a	3.31 ^a	1.51 ^b	0.507
ME used for gain, MJ/d	0.67	1.57	1.41	0.051	0.0	0.0	0.38	0.166
k _{ld} , %	63.9	57.3	54.5	3.67	68.1	67.6	67.9	1.58
k _m , %					78.0	81.7	83.5	4.98
k _l , %	69.4	67.1	66.6	2.46	75.4	77.9	78.0	3.74
ME _m , kJ/kg of BW ^{0.75}	494 ^a	471 ^a	399 ^b	22.2	429 ^a	432 ^a	358 ^b	13.9

^{a–c}Means within level of intake grouping with different superscripts differ ($P < 0.05$).

¹Ad libitum intake is based on fasting heat energy after ad libitum intake and the average efficiency of use of dietary ME for maintenance of animals at the same stage of lactation when fed near maintenance and fasted. Intake near maintenance is based on fasting heat energy after intake near maintenance and efficiency of use of dietary ME for maintenance based on ME intake and heat energy corrected for that from use of tissue energy for lactation when fed near maintenance and fasted.

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 ME for lactation; k_m = efficiency of use of dietary ME for maintenance; k_l = efficiency of energy use for maintenance and lactation.

³Based on BW during the periods of consumption ad libitum or near maintenance rather than during the fasting period.

⁴Use of tissue for lactation = 16% of mobilized tissue energy lost as heat when used for lactation.

⁵Gain = 25% of dietary ME lost as heat when used for tissue gain.

stages of lactation in digestibilities of does fed near ME_m.

Energy Utilization

Intake of ME was similar among stages of lactation for does consuming ad libitum and near ME_m (Table 4). In does consuming ad libitum, urinary energy was lowest among stages of lactation in mid lactation ($P < 0.05$), whereas in does consuming near ME_m, urinary energy was lower in early and mid lactation than in late lactation ($P < 0.05$). Methane emission was considerably less with consumption near ME_m than with ad libitum. Methane emission was approximately twice as great in late lactation than in early and mid lactation in does consuming ad libitum, and methane emission was markedly lower in early lactation compared with

mid and late lactation ($P < 0.05$) in does consuming near ME_m.

Tissue energy change, accretion or loss, was similar among stages of lactation and not different from 0 for does consuming ad libitum (Table 4). However, tissue energy change was considerably lower (i.e., greater mobilization) for does fed near ME_m in early and mid lactation compared with late lactation ($P < 0.05$). Total HE was similar among stages of lactation for does consuming ad libitum and near ME_m. Fasting HE in (kJ/kg of BW^{0.75}) tended to differ among stages of lactation for does consuming ad libitum ($P < 0.10$) and near ME_m ($P < 0.09$). Values for both levels of intake tended to be lower in late lactation compared with early and mid lactation. Fasting HE averaged 42 kJ/kg of BW^{0.75} and 13% greater ($P < 0.05$) for does consuming ad libitum compared with those consuming near ME_m.

Stage of lactation did not affect ME_m (MJ/d) for does consuming ad libitum or near ME_m (Table 4). Because differences were found in ME_m , expressed in kilojoules per kilogram of $BW^{0.75}$, the lack of differences (MJ/d) were largely the result of differences in BW. The ME_m (kJ/kg of $BW^{0.75}$) for both levels of intake was lowest among stages for late lactation ($P < 0.05$). In kilojoules per kilogram of $BW^{0.75}$, ME_m was greater ($P < 0.05$) with ad libitum consumption than with near ME_m consumption. In does consuming ad libitum, HE_{ld} , HE_{lt} , and HE_g were similar among stages of lactation, as was true for does fed near ME_m , except for greater HE_{lt} in early and mid lactation compared with late lactation ($P < 0.05$). 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 with ad libitum intake [$RE = -250.2 + (0.5754 \times MEI)$; $R^2 = 0.85$] yielded an ME_m of 435 kJ/kg of $BW^{0.75}$, which was fairly similar to the average of treatment means in the present experiment for does consuming ad libitum (i.e., 455 kJ/kg of $BW^{0.75}$).

Total RE was greater in early lactation than in late lactation for does consuming ad libitum ($P < 0.05$) but was similar among stages of lactation for does fed near ME_m (Table 4). Recovered energy in milk for does consuming ad libitum was lowest among stages of lactation in late lactation ($P < 0.05$) and for does fed near ME_m RE_l was similar among stages of lactation. However, RE_{ld} ranked ($P < 0.05$) early > mid > late lactation in does consuming ad libitum, with no differences among stages of lactation in does fed near ME_m . The RE_{lt} for does fed near ME_m was lowest among lactation stages in late lactation ($P < 0.05$), but for does consuming ad libitum RE_{lt} was not affected by lactation stage. Stage of lactation did not influence RE_g with either level of intake.

Dietary ME used for lactation (ME_{ld}) was similar among stages of lactation for does consuming ad libitum and near ME_m (Table 4). Mobilized tissue energy used in lactation (ME_{lt}) was similar among stages of lactation for does consuming ad libitum but was lowest among lactation stages in late lactation ($P < 0.05$) for does fed near ME_m . Dietary ME used for tissue gain (ME_g) was similar among stages of lactation for both levels of intake. Also, k_{ld} and k_l were not affected by stage of lactation with either level of intake, as was true for k_m estimated in does fed near ME_m as well. Does fed near ME_m had considerably greater k_{ld} and k_l than does consuming ad libitum ($P < 0.05$). With the approach of Freetly et al. (2006) for beef cows of regressing RE_{ld} against ME_{ld} to estimate k_{ld} , data of does consuming ad libitum resulted in a value of 52.8% [$RE_{ld} = 0.6145 + (0.5283 \times ME_{ld})$; $R^2 = 0.57$], which

was slightly less than the average of treatment means in this experiment.

DISCUSSION

Milk Yield and Composition

Differences in milk yield between each stage of lactation contrast findings of Tovar-Luna et al. (2010) with the same diet. In that experiment, milk yield was similar between early and mid lactation and lowest for late lactation. Furthermore, average milk yield by does consuming ad libitum in early lactation in the present experiment was considerably greater than noted by Tovar-Luna et al. (2010; i.e., 3.61 vs. 2.87 kg/d). Although parity did not affect milk yield in this earlier experiment, inclusion of some primiparous animals compared with all multiparous does in the present experiment might have contributed to the difference in milk yield. On an absolute basis, the magnitude of difference in milk yield between levels of feed intake in the present experiment was substantial. However, that milk production with the level of intake near ME_m averaged almost 50% of yield with ad libitum consumption depicts the high metabolic priority given to lactation. The much greater difference in fat concentration between does consuming ad libitum and near ME_m in late lactation than in early or mid lactation suggests that a longer period of time at a restricted level of intake would have been required to markedly alter metabolic processes limiting milk fat production relative to other constituents such as protein.

Intake and Digestion

Ad libitum DMI was considerably greater during early and mid lactation compared with the same stages of lactation addressed by Tovar-Luna et al. (2010), although DMI in late lactation was similar. Body weight did not seem involved in these differences, being slightly greater in the Tovar-Luna et al. (2010) experiment during early lactation (50.4 vs. 47.1 kg), similar in mid lactation, and lower in late lactation (51.7 vs. 55.2 kg).

Similar OM digestibility in animals fed near ME_m in the present experiment and the previous study of Tovar-Luna et al. (2010) suggests that rate of digesta passage was also comparable. Differences in OM digestibility between levels of intake were slightly greater in the present experiment than in the previous experiment. With the switch from ad libitum to near maintenance intake in the present experiment, a decrease in ruminal residence time of digesta is likely. Digestive

tract capacity for storage and transit of digesta should have been relatively high during ad libitum consumption, which could have extended into the period of near ME_m feeding. Nonetheless, the relatively high level of concentrate in the diet implies that ruminal residence time of digesta did not have marked effect on extent of OM digestion compared with a diet higher in forage. However, differences in NDF digestibility between levels of intake considerably greater in this experiment than in the earlier experiment support some influence on digestion of ruminal digesta residence time.

Digestibility of N or CP for does consuming ad libitum were as predicted based on 88% true protein digestibility and metabolic fecal CP of 2.67% of DMI (Moore et al., 2004). Conversely, observed N digestibilities in does fed near ME_m were greater than prediction of 72 to 74%. With ad libitum intake preceding near ME_m intake, because of potential carryover effects, sloughed epithelial cells and microbial cell debris could have been greater than if feed intake had been continuously restricted. Relatively long digestive tract residence time of digesta in the present experiment when does were fed near ME_m could have allowed more thorough protein digestion than a continuous level of limited feed intake would have allowed.

Energy for Maintenance

The difference between levels of intake in fasting HE (kJ/kg of $BW^{0.75}$) was anticipated but the magnitude was unknown. The 8-d period of consumption near ME_m , with 6 d before fed HE measurement preceding fasting, should have decreased energy use by support tissues such as the gastrointestinal tract and liver. The specific length of feeding near ME_m presumably influenced the size of such shifts. Smaller change in total HE and origin of HE may have been elicited by shorter lengths and, likewise, greater changes could have been incurred with longer restricted feeding. Longer periods of feeding near ME_m were avoided to retain relevance and justifiable application of the estimate of k_m to fasting HE of does immediately after ad libitum consumption. Shorter periods of intake near ME_m would probably have decreased k_m , increased k_{ld} , and increased ME_m , depending on concomitant change in fasting HE. Such change in ME_m would have resulted from decreased k_m as well as increased fasting HE, supported by the difference in fasting HE between intake levels with the current restricted feeding period of 8 d.

Average k_m (81%) was considerably greater than determined by Tovar-Luna et al. (2010) with dry animals continually fed the same diet near ME_m (i.e., 66%). Fasting HE of does fed near maintenance in this experiment (i.e., 326 kJ/kg of $BW^{0.75}$) and dry animals

consuming the 60% concentrate diet in the Tovar-Luna et al. (2010) study (i.e., 332 kJ/kg of $BW^{0.75}$) was similar. The end result in this experiment of fasting HE and k_m was considerably lower ME_m of lactating does fed near maintenance (406 kJ/kg of $BW^{0.75}$) compared with dry animals of Tovar-Luna et al. (2010; 504 kJ/kg $BW^{0.75}$). This difference in ME_m might be considered the converse of that expected. Likewise, there was an expectation of lower rather than similar fasting HE of dry animals compared with lactating does fed near ME_m . These disparities could relate to carryover effects of ad libitum intake by does of the present experiment on efficiency of splanchnic tissue metabolism. For example, Goetsch (1998) determined, based on splanchnic tissue HE by sheep consuming forage-based diets ad libitum, that efficiency of splanchnic tissue metabolism (i.e., splanchnic tissue HE per unit of DE intake or energy absorption) increases with increasing DE intake. Despite the marked reduction in HE when does were fed near ME_m relative to HE with ad libitum consumption, further decline when fasted was limited to the extent of basal metabolism existent in dry does continuously fed near ME_m of Tovar-Luna et al. (2010). Because of a suspected greater proportion of total HE attributable to support tissues such as the gastrointestinal tract and liver when animals were fed near ME_m than when fasted in a postabsorptive stage, these findings imply much greater effect of the restriction of feed intake on support tissue HE during near ME_m feeding than on all metabolic processes contributing to HE while fasting.

Differences between levels of intake in ME_m were generally as expected, with lower values for does fed near ME_m than for those consuming ad libitum, for reasons addressed earlier. Differences in ME_m between lactating does consuming ad libitum and near ME_m (455 and 406 kJ/kg of $BW^{0.75}$, respectively) and by nonlactating does of Tovar-Luna et al. (2010; 504 kJ/kg of $BW^{0.75}$) exemplify complexities in determining most appropriate means of study of energy metabolism by lactating dairy goats. Employment of the latter ME_m would result in a relatively high estimate of k_{ld} (e.g., 63.2% in Tovar-Luna et al., 2010). Rather than use of the relatively low ME_m of does fed near ME_m in the present experiment not directly applicable to does consuming ad libitum, a compromise approach was employed. Application of k_m determined for does fed near ME_m to fasting HE of does consuming ad libitum resulted in an average k_{ld} of 58.3%, similar to the value determined by Nsahlai et al. (2004; i.e., 59%) from regression analysis with a database of treatment mean observations from the literature. A lower k_{ld} would have resulted from direct use of the ME_m of does fed near ME_m .

Similar ME_m (MJ/d) among stages of lactation indicates that BW was largely responsible for the difference

(kJ/kg of $BW^{0.75}$) in ME_m between late lactation and early and mid lactation. Based on findings of Ngwa et al. (2009), most of the difference in BW among stages of lactation probably involved level of body fat, which may have a lower energetic cost of maintenance than protein (Webster, 1981; Birnie et al., 2000). This could be one reason for some of the dissimilar findings of Tovar-Luna et al. (2010). Nonlactating animals in the previous experiment would not be expected to mobilize or accrete appreciable tissue compared with lactating animals. However, other factors might have contributed to relatively low ME_m (kJ/kg of $BW^{0.75}$) during late lactation. One possibility is an effect of season, although relevant research has not been consistent (NRC, 2000, 2007). It is also possible that level of basal metabolism in addition to that of support tissues varies in accordance with level of milk secretion.

Energy for Lactation

Estimates of HE_g , RE_g , and ME_g for animals consuming ad libitum were greater than in the previous experiment of Tovar-Luna et al. (2010) with the same diet. With similar BW among stages of lactation in the previous experiment, it was stated that a higher plane of nutrition later would be necessary before successful rebreeding, gestation, and the subsequent lactation. A less marked improvement in the plane of nutrition following the present experiment would be needed because of apparent tissue energy accretion throughout lactation, albeit numerically greater in mid and late lactation than early lactation.

As anticipated, the decline in HE_{ld} during the period of intake near ME_m was partially compensated for by increased HE_{lt} . Reasons for much higher k_{ld} in does consuming near ME_m than in those consuming ad libitum include reasons addressed earlier for a higher k_m compared with nonlactating animals of Tovar-Luna et al. (2010) continuously fed near ME_m . In addition, a possible contributing factor is a greater efficiency of use of mobilized tissue energy than the 84% assumed, relevant to HE both while being fed near ME_m and fasting but with varying potential magnitudes of influence. This difference in k_{ld} between levels of intake provides possible reasoning for the slightly low k_{ld} estimate of Nsahlai et al. (2004), recommended by NRC (2007), relative to other values and predictions for goats (AFRC, 1998). Observations used by Nsahlai et al. (2004) were of animals with ad libitum or near ad libitum intake. Databases used to derive efficiencies of energy use for lactation with restricted levels of intake might be expected to yield greater k_{ld} estimates.

Similar to potential influence of the assumption of the efficiency of use of mobilized tissue energy for lactation,

the value used for efficiency of utilization of dietary ME for tissue energy accretion could have contributed to decreasing k_{ld} in does consuming ad libitum as stage of lactation advanced. For example, in dairy cattle Kebreab et al. (2003) calculated a much greater efficiency of 83 to 86% than employed in the present experiment. Use of a value in this range would have increased k_{ld} in mid and late lactation relative to early lactation. Furthermore, data of Ngwa et al. (2009) suggest that because of change in fat concentration in tissue accreted as stage of lactation advanced, true efficiency of energy use for tissue energy gain may be greatest in late lactation.

In the previous experiment, Tovar-Luna et al. (2010) concluded that because of differences in k_m , k_{ld} , and ME_m among early, mid, and late stages of lactation based partially on data from nonlactating animals fed near ME_m , k_l could be preferable to k_m and k_{ld} when evaluating efficiency of energy utilization for lactating goats. Though perhaps to a somewhat lesser extent, the same can be suggested based on findings of this experiment. That is, compensatory differences among stages of lactation in ME_m and k_{ld} (numerical) resulted in similar k_l among stages of lactation. As noted by Tovar-Luna et al. (2010), one efficiency has the attribute of avoiding the challenging task of justifying specific methods employed for partitioning of k_l into k_m and k_{ld} . However, the decision to use one efficiency of energy use for lactation does not fully address questions regarding most appropriate means of quantifying ME_m . But with some evaluation systems, ME_m is irrelevant, with efficiency of dietary ME use for lactation expressed as RE_{ld} relative to MEI corrected for ME_g (Kebreab et al., 2003).

CONCLUSIONS

Fasting HE (kJ/kg of $BW^{0.75}$) by does consuming near ME_m was lowest in late lactation, with a similar numerical difference when consumption was ad libitum. Fasting HE was 42 kJ/kg of $BW^{0.75}$ and 13% greater with ad libitum than with near ME_m intake. The k_m determined with does consuming near ME_m was similar among stages of lactation and averaged 81%. From fasting HE and k_m determined with does fed near ME_m , ME_m (kJ/kg of $BW^{0.75}$) was lower in late lactation than in early and mid lactation for both levels of intake and was greater for ad libitum than for near ME_m consumption (49 kJ/kg of $BW^{0.75}$ and 12%). The k_{ld} was greater for near ME_m than for ad libitum consumption, with ad libitum consumption k_{ld} numerically ranked as follows: early > mid > late lactation. The k_l was very similar among stages of lactation with both levels of intake and was greater for intake near ME_m than for intake

ad libitum. With similar ME_m expressed in megajoules per day, differences among stages of lactation ($\text{kJ/kg of BW}^{0.75}$) in ME_m may have been attributable to tissue energy retention throughout lactation resulting in different BW and perhaps body composition in late lactation than in early and mid lactation. The ME_m requirement ($\text{kJ/kg of BW}^{0.75}$) of does in late lactation may be less than that of does in early and mid lactation. Method of determination can influence estimates of k_m and k_{ld} , with marked effect of restricted feed intake subsequent to ad libitum consumption compared with use of nonlactating animals fed near ME_m . Level of feed intake can have substantial effect on estimates of energy utilization by lactating dairy goats.

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