



Metabolizable energy requirements of lactating goats

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Abstract

Data from 44 studies with 243 treatment mean observations, representing 2476 goats in various stages of lactation, were used to estimate the requirement and efficiency of use of ME for milk production. Development and evaluation data subsets comprised, respectively, 68 and 32% of observations. ME intake was also adjusted for energy lost in excretion of excess nitrogenous compounds in urine (ME_{EXN}), as 62.21 kJ/g of N intake above endogenous urinary N ($0.165 \text{ g/kg BW}^{0.75}$). Adjusted ME intake was partitioned into that used for maintenance and activity in pen or stall settings (ME_m ; by two methods), ME secreted in milk and ME gained as BW. For Method 1, $ME_m = 1.1 \times 315 \text{ kJ/kg BW}^{0.75}/k_m$, with k_m or efficiency of ME use for maintenance = $0.503 + (0.019 \times ME, \text{ MJ/kg DM})$. For Method 2, estimates of ME_m in a companion study for dairy ($501.3 \text{ kJ/kg BW}^{0.75}$) and other goat biotypes ($422.7 \text{ kJ/kg BW}^{0.75}$) were used. When BW increased, ME intake was adjusted for tissue accretion (efficiency = 0.75) to derive dietary ME used in milk secretion (ME_{I-d}). Milk yield was corrected to 4% fat [4% FCM; $\text{MJ/kg} = 1.4694 + (0.4025 \times \% \text{ milk fat})$]. For does decreasing in BW, FCM from the diet (FCM_d) was estimated by adjusting for use of mobilized tissue energy (23.9 kJ/g; efficiency = 0.84). No particular equations explained considerably more variability in observed FCM or NE for lactation than other equations. Based on no-intercept regressions (ME_{I-d} against FCM_d) with Method 1, the dietary ME requirement for lactation was 4598 (S.E. = 106.6) and 4937 (S.E. = 106.5) kJ/kg FCM with and without adjustment for ME_{EXN} , respectively. With Method 2 and no-intercept equations, the dietary ME requirement for lactation was 4882 (S.E. = 105.2) and 5224 (S.E. = 105.8) kJ/kg FCM with and without adjustment for ME_{EXN} , respectively. Prediction accuracy was similar between methods and improved slightly by correction for ADG. In conclusion, with the large amount of data employed in this study, these estimates and this factorial approach seem useful to predict energy requirements of lactating goats, with potential for future enhancements based on research of the factorial approach assumptions.

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1. Introduction

The productivity and long-term viability of any animal production system largely depends on quality of the animals and environmental factors. One of the most important environmental factors is the diet because feeds can limit productivity in terms of quality, quantity and distribution within the year. However, dairy animals are often intensively farmed and as such do not suffer as frequently from seasonal changes in feed supplies compared with other classes of livestock. Nonetheless, successfully providing appropriate amounts and types of feeds to intensively farmed livestock necessitates some knowledge of nutrient requirements. Moreover, nutrient requirements are not static, but can change with genetic selection and crossbreeding. Furthermore, physiological state of the animal influences nutrient requirements. Consequently, livestock nutrient requirements must be periodically reviewed and reevaluated, the success of which is primarily dictated by the availability and quality of research results.

Because of the importance of adequate nutrition to high levels and efficiencies of goat production, this topic has received an appreciable amount of research emphasis in the last 20 years. However, since the last NRC (1981) report for goats, there has not been a thorough compiling in the US of data from feeding and nutrition experiments with goats for use in describing animal nutrient requirements. In fact, a revision of nutrient requirements for lactating goats was suggested by Randy et al. (1988) more than 10 years ago, which in part may be because the NRC (1981) ME requirement for lactating goats was based on four experimental values. Therefore, the objective of this research was to compile literature data and evaluate ME requirements of lactating goats.

2. Materials and methods

2.1. Database

Data were collected from published literature and assessed for suitability in determining nutrient requirements of lactating goats; data meeting prescribed criteria were retained. Retention of data in the database depended on information in the report concerning milk

yield (kg), BW (kg), ADG (g/day) and ME intake (kJ/day). For studies in which mean BW was not presented, an average of initial and final BW was used as mean BW. If ADG was provided in addition to either initial or final BW, these values and the duration of the experiment were used to estimate mean BW. In some instances, fecal and urine collections were performed, which along with an assumption of methane loss allowed for a direct determination of ME intake. However, in most cases ME intake was estimated from dietary ingredient composition and ME concentrations in feedstuffs in diets from literature sources, either by authors of the original report or calculated in this study. A detailed description of how dietary ME concentration was estimated is in a companion report (Luo et al., 2004b). There were 49 reports or references and 296 treatment mean observations with estimates of 4% fat-corrected milk (4% FCM); 44 of these reports met the eligibility criteria. In order to use data from four eligible studies for which milk composition was not listed, milk fat composition was estimated from the other data. Because milk composition can vary with both breed and stage of lactation, milk composition means were calculated for different breeds and phases of lactation (i.e., early lactation, weeks 1–10; mid-lactation, weeks 11–20; late lactation, > weeks 20; Table 1). These values and milk yield were used to estimate missing FCM data.

The 44 eligible reports comprised 243 treatment mean observations derived from 2476 goats. These studies were randomly separated into two subsets—one for prediction equation development and the other for evaluation. The development subset comprised 34 reports with 170 treatment mean observations derived from 1605 goats (Table 2).

2.2. Dietary NE secreted in milk and FCM arising from dietary NE

Energy secreted in milk, i.e., NE for lactation (NE_l, kJ/day), was calculated from milk yield and milk fat concentration with the equation of NRC (1989) for dairy cattle: $NE_l \text{ (MJ/kg)} = 1.4694 + (0.4025 \times \% \text{ fat in milk})$. Does typically lose BW during early lactation, which is normally recouped later. This means that NE_l can arise from energy of both feed and catabolized body tissue. In order to estimate NE_l from the diet alone (NE_{l-d}), it was assumed based on AFRC (1993,

Table 1
Summarized milk composition (mean \pm standard deviation) of goats during different phases of lactation

Breed	Phase ^a	n	Milk constituent (%)		
			Fat	Protein	Total solids
Alpine	1	94	3.60 \pm 1.990	2.89 \pm 0.515	11.1 \pm 2.49
	2	62	3.53 \pm 1.172	2.77 \pm 0.582	10.8 \pm 0.06
	3	18	3.92 \pm 2.082	3.33 \pm 0.677	
Saanen	1	7	3.26 \pm 1.477	3.04 \pm 0.257	10.4 \pm 0.76
	2	2	3.34 \pm 0.325	2.99 \pm 0.085	
	3	4	4.50 \pm 1.428	3.84 \pm 0.198	
Nubian	1	4	4.23 \pm 0.619	2.59 \pm 0.439	8.3 \pm 0.77
	2	4	4.38 \pm 0.536		
Damascus	1	21	4.32 \pm 1.388	4.11 \pm 1.328	13.3 \pm 1.53
	2	29	4.86 \pm 2.160	4.33 \pm 1.626	13.6 \pm 1.82
	3	6	3.91 \pm 0.866	4.17 \pm 0.269	
Granadina	1	1	5.94	3.18	14.7
	2	11	5.98 \pm 0.949	3.40 \pm 0.259	15.2 \pm 1.182
	3	4		4.74 \pm 0.441	19.8 \pm 2.40
Angora	1	4	5.23 \pm 0.946	4.11 \pm 0.118	
Dwarf east African goat, Moroccan goat	2	5	3.92 \pm 1.119	3.44 \pm 1.534	13.6 \pm 2.55
Indigenous/feral	1	16	5.94 \pm 3.116	4.45 \pm 1.037	17.7 \pm 1.09
Crossbreed (indigenous \times dairy)	2	6	3.46 \pm 1.024	3.53 \pm 0.734	11.4 \pm 0.50
Other dairy	1	15	3.99 \pm 0.773	2.99 \pm 0.365	
	2	14	3.49 \pm 0.862	3.15 \pm 0.282	
	3	8	3.95 \pm 0.486	2.99 \pm 0.142	
Swedish landrace	2	10	3.67 \pm 0.500	3.01 \pm 0.339	11.6 \pm 0.75

^a 1: 1–10 weeks; 2: 11–20 weeks; 3: >20 weeks.

1998) that mobilized tissue contained 23.9 MJ/kg and energy from mobilized tissue was used with an efficiency of 84% for milk synthesis (NE_{l-t} , kJ/day). Hence, NE_{l-d} was calculated as the difference between NE_l and NE_{l-t} . Likewise, FCM arising from NE_{l-d} alone (FCM_d ; kg/day) was estimated.

2.3. Dietary ME available for milk synthesis

A first step in estimating ME from the diet used for milk synthesis was to subtract the maintenance plus activity requirement (ME_m) from total ME intake. This was accomplished by two approaches or methods. For Method 1, ME_m was derived with AFRC (1998) recommendations for the NE for maintenance requirement (NE_m ; 315 kJ/kg $BW^{0.75}$), energy used for activity in a pen or stall environment (10% of

NE_m) and efficiency of ME use for maintenance [k_m ; $0.503 + (0.019 \times ME, \text{ MJ/kg DM})$]. The average ME concentration in diets of the database was 10.5 MJ/kg DM (S.D. = 0.95; range = 7.1–12.9), and mean k_m was 0.70 (S.D. = 0.018; range = 0.64–0.75). The ME requirement for production (ME_p) was calculated by subtracting ME_m from ME intake.

Method 2 for estimating the ME_m requirement was based on findings of Luo et al. (2004b). Luo et al. (2004b) estimated ME_m requirements for growing dairy and indigenous goats biotypes of 580 and 489 kJ/kg $BW^{0.75}$, respectively; the ME_m for mature goats with a relatively small database was 462 kJ/kg $BW^{0.75}$. Assuming that relative differences between biotypes in ME_m of growing goats was maintained to maturity (NRC, 2000), mature dairy and indigenous goats would have a ME_m requirement of 501.3 and 422.7 kJ/kg $BW^{0.75}$, respec-

Table 2
Summary of the development data subset

Reference ^a	Source	Forage		Breed ^c	Live weight (kg)	ADG (g/day) ^d		FCM ^e range (kg/day)
		Type ^b	%			Min	Max	
445	Andrade et al., 1996	AH + FS		3	40.7–43.7	–80.0	30.0	1.10–1.33
428	Aguilera et al., 1990	Pelleted AH	35–40	7	34.1–40.6	–49.3	78.7	1.40–1.89
751	Ciszuk and Lindberg, 1988	Hay/straw	40	20	46.8–53.6	–66.0	125.0	1.75–2.52
140	Economides, 1986	AH	32–38	5	44.0–68.8	13.3	66.7	2.91–4.31
827	Fernandez et al., 1988	CSH	38–43	1	42.1–62.6	–3.3	114.3	1.23–2.33
605	Goetsch et al., 2000	CSH and AH	40–80	1	35.8–59.2	15.8	93.0	1.62–3.53
53	Hadjipanayiotou, 1992	BH	22–24	5	65.2–65.9	–11.4	14.3	2.42–2.92
231	Hadjipanayiotou, 1984	BS (urea-treated)	14–17	5	63.0–63.1	2.0	5.0	1.75–1.80
233	Hadjipanayiotou, 1987	BH	24–30	5	52.0–61.0	–45.5	–3.1	2.29–2.84
320	Hadjipanayiotou, 1988b	BH	12–14	5	61.7–62.6	11.0	26.0	1.87–2.21
293	Hadjipanayiotou, 1995	50BH:50 BS	30	5	73.2–73.3	–51.9	–75.0	2.67–2.78
241	Hadjipanayiotou et al., 1988	65BH:35 AH	30	5	66.8–68.0	–26.8	–71.4	3.98–3.99
374	Hadjipanayiotou and Photiou, 1995	18BH:27BS		5	62.7–67.5	–202.0	–156.0	1.55–1.79
296	Hadjipanayiotou et al., 1996	16BS:56 BH	25	5	71.2–74.1	–199.0	47.0	2.58–3.72
367	Hong et al., 1988	AH	59–69	2	68.9	–130.0	–100.0	3.30–3.70
533	Hussain et al., 1996	Hay and silage	20–23	19	44.0–45.4	26.2	183.3	0.72–0.95
298	Kawas et al., 1991	Cunha silage	45–75	14	36.6–37.1	–50.0	120.0	0.43–0.49
349	Kiranadi et al., 1994	Grass and GS	48–60	12	20	32.6	372.4	0.08–0.21
253	Louca and Papas, 1973	AH	26	5	56.3–61.0	50.0	–77.4	2.27–2.60
258	Lu et al., 1990a	AM and CSH	40–45	1	48.6	8.0	24.0	2.01–2.31
300	Lu et al., 1990b	CSH	33–37	1	47.8	31.0	51.0	2.69–2.72
343	Lu, 1993	CSH	29–36	1	47.4	5.7	24.8	2.42–2.43
90	Qi et al., 1992	BG + GPH	43	1	65.3	–36.4	–20.8	2.65–2.81
337	Randy et al., 1988	GH			51.6–61.6	–192.0	229.3	2.23–4.00
842	Rapetti et al., 2001	Grass silage	55	2	47.0–61.5	29.0	125.0	1.89–4.37
96	Sahlu et al., 1993	AM	5	1	57.6–63.4	–29.6	2.0	3.32–3.96
828	Sahlu et al., 1999	AH + BG	22–38	8	43.0–44.3	34.9	61.8	0.69–1.06
341	Santini et al., 1991	AH	37–82	1	60.0–62.0	7.1	100.0	4.28–5.46
94	Santini et al., 1992	AH	37–82	1	62.0–65.0	–80.0	–40.0	3.30–3.50
657	Sanz Sampelayo et al., 1998	AH (long/pelleted)	44–49	7	49.1–49.7	–67.4	–33.7	1.80–1.83
350	Sastradipradja et al., 1994	Grass	25–39	12	21.5	–68.0	19.0	0.28–0.55
726	Schiavon et al., 1996	GH	20	1	51.4	23.0	23.0	1.49
412	Sibanda et al., 1997	GH and AH		12	35.1–41.0	–9.0	59.0	0.75–1.31
342	Teh et al., 1994	CSH	19–20	1	48.2–54.8	–39.6	110.3	4.22–4.58

^a Database reference number.

^b AH: alfalfa hay; FS: forage sorghum; CSH: cottonseed hulls; BH: barley hay; BS: barley straw; GS: grass silage; AM: alfalfa meal; BG: bermudagrass; GPH: ground peanut hulls; GH: grass hay; listed numbers are percentages of DM.

^c 1: Alpine; 2: Saanen; 3: Nubian; 5: Damascus; 7: Granadina; 8: Angora; 12: indigenous feral; 14: crossbred (indigenous × dairy type); 19: other dairy; 20: Swedish landrace.

^d Min: minimum; max: maximum.

^e FCM: 4% fat-corrected milk.

tively. An adjustment of ME_m for the state of lactation (compared with nonlactating animals) of [NRC \(2000\)](#) (i.e., 20% greater) was tested but found to lead to poor relationships compared with those derived without adjustment.

In addition to using ME intake above ME_m for milk production, ME can be used for tissue accretion, ex-

cretion and fiber growth. Consequently, for does increasing in BW, the [AFRC \(1993\)](#) recommendation for the energy concentration in tissue gain (23.9 MJ/kg) and the [NRC \(1989\)](#) recommendation for efficiency of use of dietary ME in tissue deposition ($k_g = 0.75$) by lactating dairy cattle were employed to calculate ME used for gain (ME_g) and accreted energy (NE_g). ME_g

was subtracted from ME_p to estimate the remaining amount of ME from the diet available for milk synthesis (ME_{l-d}).

Metabolizability of energy in feedstuffs is typically determined at or near the maintenance level of nutrient intake and at or near N equilibrium, the point at which N intake and excretion are equal. However, in order to meet production needs, goats often consume N in excess of the equilibrium point, resulting in considerable excretion of urinary N, principally as urea. Energy in urinary N above endogenous urinary N (EUN) conceivably could be used in other productive functions. Given the very wide range in CP concentration in the database (i.e., 9.9–19.9%), an approach similar to that of Tyrrell et al. (1970) was used to derive the energy cost of excretion of excess N.

The EUN estimate of 0.165 g/kg BW^{0.75} for goats proposed by Luo et al. (2004a) was applied. Urinary N above EUN was assumed to be excess urinary N (ExUN, g/day). However, there were only 81 treatment mean observations in which urinary N output was listed, including ones from four reports (Manik and Sastradipradja, 1989; Baracos et al., 1991; Andrighetto and Bailoni, 1994; Brun-Bellut, 1997) that did not meet selection criteria for use in estimating the ME requirement for lactation. The dietary CP concentration ranged from 36 to 214 g/kg DM. It is expected that for a given dietary CP concentration, urinary N output increases with increasing maturity and thus BW of the animal. This pattern of variation in urinary N in theory should vary with dietary CP concentration, resulting in a family of curves. Given that the behavior of this relationship was not known, both multiple regression and non-linear regression procedures were tested; the latter accounted for 13% more variation than the former. Thus, a non-linear regression of ExUN on dietary CP concentration (%) and BW was fitted and used to derive ExUN for observations where urinary N was not listed:

$$\begin{aligned} \text{ExUN} &= 0.555(\text{S.E.} = 0.1401) \\ &\quad \times \text{BW}^{0.048}(\text{SE}=0.0037) \times \text{CP}, \\ n &= 81, R^2 = 0.72 \end{aligned} \quad (1)$$

Nine treatment mean observations from the database had estimates of both urinary N and energy. A regression of urinary energy against N ($n = 9$; adjusted- $R^2 = 0.95$) indicated that the energy content of urine

was 33.01 (S.E. = 0.943) kJ/g of urinary N; this is very similar to a value of 34 used by Katipana and Sastradipradja (1994) and Astuti et al. (1998). Moreover, Emmans (1994) estimated that 29.2 kJ of heat energy is released per gram of urinary N. Thus, 62.21 kJ/g of N was multiplied by ExUN to estimate ME lost in ExUN (ME_{ExN} , kJ/day). ME_{ExN} was subtracted from ME_{l-d} to derive a value adjusted for loss of energy with excretion of excess N.

2.4. Efficiency of use of total and dietary ME_p and ME_m plus ME_p

With both methods, NE for production [$NE_p = NE_l$ plus deposited tissue energy (NE_g)] was regressed against ME_p to estimate efficiency of use of ME_p (k_p). Similarly, efficiency (k_{p-d}) of use of dietary ME for production (ME_{p-d}) was derived by regressing NE_p from the diet ($NE_{p-d} = NE_{l-d} + NE_g$) against ME_{p-d} . Also, NE for maintenance plus production ($NE_{mp} = NE_m + NE_p$) was regressed against total ME_m plus ME_p (ME_{mp}) and ME_m plus dietary ME for production (ME_{mp-d}) to obtain combined efficiencies for production (k_{mp} and k_{mp-d} , respectively). k_{p-d} and k_{mp-d} were derived using data of animals that were not losing BW, and efficiencies were estimated without and with adjusting for ME_{ExN} . Because over one-half of the data was derived from genotypes of goats selected for milk production, dummy variables were used to test for this potential effect [$B_{\text{dummy}} = 1$ for dairy goat biotypes and 0 for others; $S_{\text{dummy}} =$ product of available energy input (i.e., independent variable; ME_p , ME_{p-d} , ME_{mp} or ME_{mp-d}) and B_{dummy}].

2.5. Statistical analyses

All analyses and data derivation steps were performed with SAS (1990). Regressions were not weighted by the number of observations per treatment mean. ME_{l-d} (kJ/day) was regressed against FCM_d to estimate dietary energy required to synthesize 1 kg of FCM. The efficiency with which ME_{l-d} was used for milk synthesis (k_{l-d}) was derived by regressing NE_{l-d} (kJ/day) against ME_{l-d} (kJ/day), and also indirectly by regressing ME_{l-d} against NE_{l-d} . Regressions were fitted for ME_{l-d} and NE_{l-d} both with and without adjustment for ME_{ExN} . Models with and without intercepts were implemented because in principle intercepts

should be zero. To improve model fit, observations for which the magnitude of the residuals exceeded two times the root mean square error (R.M.S.E.) were omitted from analyses, and regressions were refitted.

Based on the pattern of scatter plots of residuals of ME_{l-d} and NE_{l-d} and presence of some positive intercepts, as noted below, a further investigation entailed use of multiple regressions of ME intake (kJ/kg $BW^{0.75}$) against ADG (g/kg $BW^{0.75}$), FCM (kg/kg $BW^{0.75}$) and (or) NE_l (kJ/kg $BW^{0.75}$).

Equations derived from the development data subset were used to predict values for the evaluation data subset. Observed values were regressed on predictions to determine whether intercepts and slopes equaled zero and one, respectively (Montgomery and Peck, 1982); an equation with an intercept of zero and slope of one indicates good fit.

3. Results

3.1. ME_{l-d}/FCM_d and k_{l-d} with Method 1

Fig. 1 depicts relationships between ME_{l-d} and FCM_d and NE_{l-d} for the development data subset based on Method 1. Eqs. (2) and (3) (Table 3) were obtained by regressing ME_{l-d} (kJ/day) against FCM_d (kg/day) after adjusting for ME_{ExN} and without adjustment, respectively. Intercepts for both equations did not differ ($P > 0.05$) from zero. When regressions were forced to pass through the origin, differing ($P < 0.05$) slopes were 4598 (S.E. = 106.6) and 4937 (S.E. = 106.5) kJ/kg $BW^{0.75}$ with and without adjusting for ME_{ExN} , respectively.

The efficiency of utilization of ME_{l-d} for lactation was first derived by regressing NE_{l-d} (kJ/day) against ME_{l-d} (kJ/day); this resulted in Eqs. (4) (af-

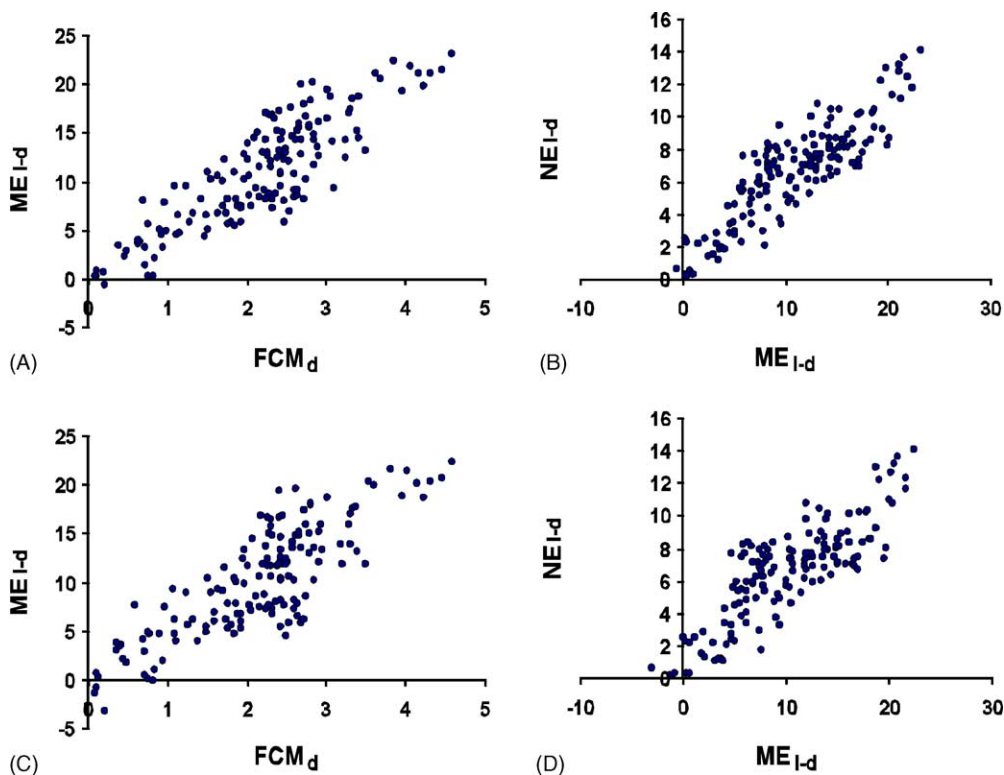


Fig. 1. Relationships with the development data subset between 4% fat-corrected milk (FCM_d ; kg/day) from the diet and dietary ME for lactation (ME_{l-d} ; MJ/day), and between dietary NE for lactation (NE_{l-d} ; MJ/day) and ME_{l-d} (MJ/day) without (A, C) and with (B, D) correction for energy lost in excretion of excess N, respectively. Based on Method 1, with use of assumptions of AFRC (1998) to predict ME for maintenance and activity.

Table 3

Relationships among ME for lactation (ME_{l-d} , kJ/day), 4% fat-corrected milk (FCM_d , kg/day) and NE of lactation derived from the diet (NE_{l-d} , kJ/day)

Equation	Dependent variable ^b	Independent variable	Estimate ^a		R.M.S.E. ^b	Adjusted- R^2	Adjusted for excess N ^c
			Intercept	Slope			
Method 1 ^d							
2	ME_{l-d}	FCM_d	-253 (656.8)	4697 (278.7)	3145.9	0.65	Yes
3	ME_{l-d}	FCM_d	86 (650.9)	4903 (277.0)	3144.7	0.67	No
4	NE_{l-d}	ME_{l-d}	2463 (284.4)	0.43 (0.025)	1660.8	0.65	Yes
5	NE_{l-d}	ME_{l-d}	2173 (285.2)	0.42 (0.023)	1615.6	0.66	No
6	ME_{l-d}	NE_{l-d}	-253 (656.8)	1.53 (0.091)	3145.9	0.65	Yes
7	ME_{l-d}	NE_{l-d}	86 (650.9)	1.59 (0.090)	3144.7	0.67	No
Method 2 ^d							
8	ME_{l-d}	FCM_d	615 (623.5)	4639 (267.6)	3101.7	0.65	Yes
9	ME_{l-d}	FCM_d	1012 (623.9)	4825 (267.7)	3103.2	0.67	No
10	NE_{l-d}	ME_{l-d}	2006 (295.9)	0.44 (0.025)	1667.0	0.65	Yes
11	NE_{l-d}	ME_{l-d}	1725 (299.3)	0.43 (0.024)	1624.6	0.67	No
12	ME_{l-d}	NE_{l-d}	615 (623.5)	1.51 (0.087)	3101.7	0.65	Yes
13	ME_{l-d}	NE_{l-d}	1012 (623.8)	1.57 (0.087)	3103.2	0.67	No

^a Values in parentheses are S.E.

^b Root mean square error.

^c Yes: adjusted for excretion of excess urinary N; No: no adjustment.

^d Method 1: use of assumptions of AFRC (1998) to predict ME for maintenance and activity; Method 2: use of estimates of ME for maintenance and activity from Luo et al. (2004b).

ter adjusting for ME_{ExN}) and (5) (without adjustment for ME_{ExN} ; Table 3). Intercepts of Eqs. (4) and (5) were different from zero ($P < 0.01$). When regressions were forced to pass through the origin, differing ($P > 0.05$) slopes were 0.62 (S.E. = 0.014) and 0.58 (S.E. = 0.013) with and without adjusting for ME_{ExN} , respectively. Efficiency of dietary ME use for lactation can also be derived by dividing the energy concentration in FCM (3.079 MJ/kg) by slopes of no-intercept equations of Eq. (2) and (3) (e.g., NRC, 1989), resulting in k_{l-d} of 0.67 and 0.62 with and without adjusting for ME_{ExN} , respectively.

Similar to the approach used for Eqs. (2) and (3), ME_{l-d} was regressed against NE_{l-d} , resulting in Eq. (6) with adjustment for ME_{ExN} and Eq. (7) without adjustment (Table 3). Intercepts of both equations did not differ ($P > 0.05$) from zero, in contrast to intercepts of Eqs. (4) and (5). Forcing these regression through the origin yielded differing ($P > 0.05$) regression coefficients of 1.49 (S.E. = 0.035) and 1.60 (S.E. = 0.035) with and without adjusting for ME_{ExN} , corresponding to k_{l-d} of 0.67 and 0.63, respectively, as expected based on calculation by division of energy in FCM by slopes of no-intercept equations of Eqs. (2) and (3).

Plots of residuals (observed – predicted versus predicted) of ME_{l-d} and NE_{l-d} for Eqs. (2)–(5) were established with the development data subset; these showed no obvious bias in prediction. Residuals of ME_{l-d} and NE_{l-d} for no-intercept equations were plotted, again with no obvious bias noted. Also, plots of residuals of ME_{l-d} from no-intercept and intercept regressions of ME_{l-d} against NE_{l-d} did not display obvious patterns of change as observed NE_{l-d} increased. However, it was noted that the ratio of observed:predicted values in the development data subset for Eqs. (2)–(7) tended to vary with ADG. Hence, ratios were regressed against ADG (g/day) to derive multiplicative correction factors (CF1) reported in Table 4.

3.2. ME_{l-d}/FCM_d and k_{l-d} using ME_m with Method 2

Fig. 2 depicts relationships between ME_{l-d} and FCM_d and NE_{l-d} for the development data subset based on Method 2. Eqs. (8) and (9) (Table 3) were obtained by regressing ME_{l-d} (kJ/day) against FCM_d (kg/day) after adjusting for ME_{ExN} and without adjustment, respectively. Intercepts for both Equations did not differ ($P > 0.05$) from zero. When regressions

Table 4

Correction factors for ADG to predict 4% fat-corrected milk yield (CF1) and total NE of lactation (CF2) based on no-intercept versions of Eqs. (2)–(13)

Equation	Dependent variable	Independent variable ^a	Estimate ^b		R.M.S.E. ^c	Adjusted-R ²	Adjusted for excess N ^d
			Intercept	Slope			
Method 1 ^e							
2	CF1	ADG	1.077 (0.0293)	0.0017 (0.00037)	0.36	0.11	Yes
3	CF1	ADG	1.076 (0.0306)	0.0018 (0.00033)	0.38	0.11	No
4	CF1	ADG	1.158 (0.0312)	0.0019 (0.00039)	0.38	0.13	Yes
5	CF1	ADG	1.151 (0.0000)	0.0020 (0.00000)	0.40	0.13	No
6	CF1	ADG	1.077 (0.0293)	0.0017 (0.00037)	0.36	0.11	Yes
7	CF1	ADG	1.076 (0.0306)	0.0018 (0.00038)	0.38	0.11	No
Method 2 ^e							
8	CF2	ADG	1.059 (0.0296)	0.0018 (0.00037)	0.37	0.12	Yes
9	CF2	ADG	1.034 (0.0270)	0.0016 (0.00034)	0.33	0.11	No
10	CF2	ADG	1.132 (0.0316)	0.0020 (0.00040)	0.39	0.13	Yes
11	CF2	ADG	1.098 (0.0290)	0.0018 (0.00036)	0.35	0.13	No
12	CF2	ADG	1.034 (0.0230)	0.0016 (0.00034)	0.33	0.11	Yes
13	CF2	ADG	1.059 (0.0296)	0.0018 (0.00037)	0.37	0.12	No

^a ADG is live weight gain (g/day).

^b Values in parentheses are S.E.

^c Root mean square error.

^d Yes: adjusted for excretion of excess urinary N; No: no adjustment.

^e Method 1: use of assumptions of AFRC (1998) to predict ME for maintenance and activity; Method 2: use of estimates of ME for maintenance and activity from Luo et al. (2004b).

were forced to pass through the origin, differing ($P > 0.05$) slopes were 4882 (S.E. = 105.2) and 5224 (S.E. = 105.8) kJ/kg BW^{0.75} with and without adjusting for ExUN, respectively.

The efficiency of utilization of ME_{l-d} for lactation was first derived by regressing NE_{l-d} (kJ/day) against ME_{l-d} (kg/day); this resulted in Eq. (10) (after adjusting for ME_{ExN}) and in Eq. (11) (without adjustment for ME_{ExN}; Table 3). Intercepts for both Eqs. (10) and (11) were different from zero ($P < 0.01$). When regressions were forced to pass through the origin, differing ($P > 0.05$) slopes were 0.59 (S.E. = 0.013) and 0.55 (S.E. = 0.011) with and without adjusting for ME_{ExN}, respectively. Efficiency of dietary ME use for lactation was also derived by dividing the energy concentration in FCM by slopes of no-intercept equations of Eqs. (8) and (9) (e.g., NRC, 1989), resulting in k_{l-d} of 0.63 and 0.59 with and without adjusting for ME_{ExN}, respectively.

Similar to the approach used for Eqs. (6) and (7), ME_{l-d} was regressed against NE_{l-d}, resulting in Eq. (12) with adjustment for ME_{ExN} and Eq. (13) without adjustment (Table 3). Intercepts for both Eqs.

(12) and (13) did not differ ($P > 0.05$) from zero, in contrast to intercepts of Eqs. (10) and (11). Forcing these regression through the origin yielded differing ($P > 0.05$) regression coefficients of 1.59 (S.E. = 0.034) and 1.70 (S.E. = 0.034) with and without adjusting for ME_{ExN}, corresponding to k_{l-d} of 0.63 and 0.59, respectively, as expected based on calculation by division of energy in FCM by slopes of no-intercept equations of Eqs. (8) and (9).

Plots of residuals were examined as for equations of Method 1, with no obvious bias detected. It was observed with the development data subset, as for Method 1, that based on no-intercept models the ratio of observed:predicted FCM and NE_l tended to change with increasing ADG. Consequently, these ratios were regressed against ADG (g/day) to derive multiplicative correction factors (CF2; Table 4).

3.3. Predictions for the evaluation data subset

The no-intercept equations (Eqs. (2)–(13); Table 3) and their corresponding correction factors (Table 4) were used to predict FCM and NE_l (P-FCM and

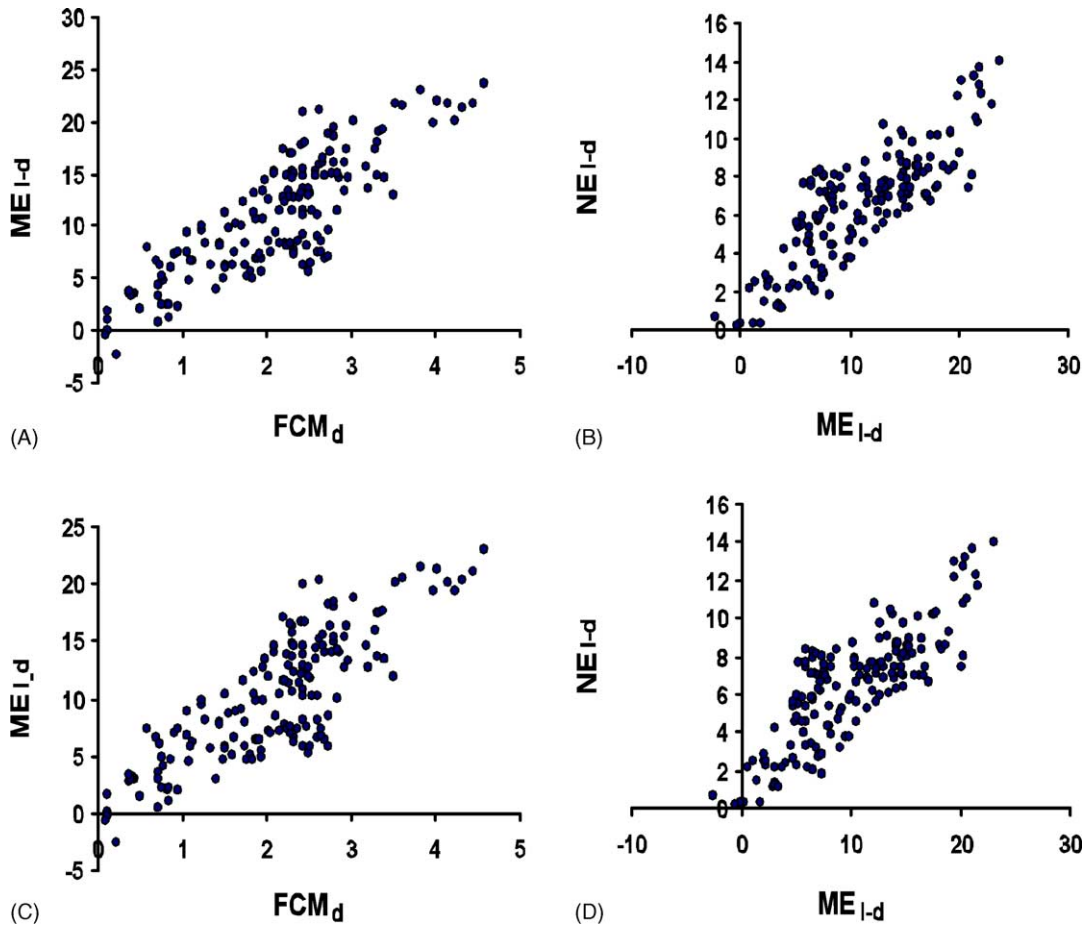


Fig. 2. Relationships with the development data subset between 4% fat-corrected milk (FCM_d ; kg/day) from the diet and dietary ME for lactation (ME_{l-d} ; MJ/day), and between dietary NE for lactation (NE_{l-d} ; MJ/day) and ME_{l-d} (MJ/day) without (A, C) and with (B, D) correction for energy lost in excretion of excess N, respectively. Based on Method 2, with use of estimates of ME for maintenance and activity from Luo et al. (2004b).

P- NE_l , respectively) in the evaluation data subset, consisting of 81 observations. Regressions of observed against predicted values resulted in equations reported in Table 5, and means of predicted and observed values for the reports in the evaluation data subset are given in Tables 6 and 7 for FCM and NE_l , respectively. Intercepts and slopes did not differ from zero and one, respectively ($P > 0.05$), except that for Eq. (6) the slope was less than one ($P < 0.05$). Adjusting for ME_{EXN} yielded results similar to those without adjustment, though judging from the slopes, adjusted- R^2 and significance of deviation of the slope and intercept from one and zero, respectively, it ap-

pears that predictions were generally slightly more accurate without the adjustment. Moreover, there appeared little difference in prediction accuracy between methods for estimating ME_m .

3.4. k_p , k_{mp} , k_{p-d} and k_{mp-d-n}

Based on no-intercept models derived with Method 1, with and without adjusting for ME_{EXN} , efficiencies were k_p : 0.66 and 0.62; k_{mp} : 0.68 and 0.66; k_{p-d} : 0.72 and 0.68; and k_{mp-d-n} : 0.72 and 0.69, respectively (Table 8). When the no-intercept models were derived with Method 2, with and without adjusting

Table 5

Regressions of observed against predicted 4% fat-corrected milk (P-FCM, kg/day) or NE of lactation (P-NE_l, kJ/day) in the evaluation data subset based on no-intercept versions of Eqs. (2)–(13) and ADG correction factors

Equation	Intercept		P-FCM		P-NE _l		R.M.S.E. ^a	Adjusted-R ²	Significance (P<) ^b	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.			Intercept	Slope
Method 1 ^c										
2	0.24	0.170	0.88	0.059			1.757	0.72	0.15	0.06
3	0.19	0.162	0.92	0.059			1.643	0.75	0.26	0.16
4	841	529.3			0.92	0.063	5493.2	0.71	0.12	0.18
5	614	508.0			0.90	0.058	5128.7	0.75	0.23	0.08
6	402	500.0			0.85	0.054	4167.0	0.76	0.42	0.03
7	578	501.8			0.91	0.058	5063.0	0.75	0.25	0.15
Method 2 ^c										
8	0.14	0.173	0.90	0.060			1.695	0.74	0.42	0.11
9	0.18	0.165	1.02	0.066			1.657	0.75	0.29	0.75
10	475	537.7			0.88	0.060	5288.6	0.73	0.38	0.06
11	558	512.7			1.00	0.065	5138.3	0.75	0.28	0.98
12	547	509.0			1.02	0.066	5104.0	0.75	0.28	0.76
13	434	531.4			0.90	0.060	5222.4	0.74	0.41	0.11

^a Root mean square error.

^b Significance of difference of the intercept from 0 and slope from 1.

^c Method 1: use of assumptions of AFRC (1998) to predict ME for maintenance and activity; Method 2: use of estimates of ME for maintenance and activity from Luo et al. (2004b).

for ME_{EXN}, efficiencies were k_p : 0.66 and 0.63; k_{mp} : 0.69 and 0.66; k_{p-d} : 0.73 and 0.68; and k_{mp-d-n} : 0.72 and 0.70, respectively. The effect of biotype was not significant ($P > 0.05$) for any efficiency. Ratios of observed–predicted NE tended to change with increasing ADG. Consequently, these ratios were regressed against ADG (g/day) to derive multiplicative correction factors (CF3) reported in Table 9.

Observed ME_p, ME_{p-d}, ME_{mp} and ME_{mp} in the evaluation data subset were regressed against predictions based on no-intercept versions of Eqs. (14)–(29) and CF3; for both methods intercepts and slopes did not differ from 0 and 1, respectively ($P > 0.05$), and explained variability was similar between methods as well (Table 10). Adjustment for ME_{EXN} did not improve predictions. Table 11 provides observed and predicted values for reports in the evaluation data subset.

3.5. Regression relationships among variables

Estimates of k_l and ME/FCM (kJ/kg) based on multiple regression analysis were, respectively, 0.70 and 4384 (Table 12; Eqs. (30) and (31)) without correcting for ME_{EXN}, and 0.72 and 4298 (Table 12; Eqs. (32) and

(33)) after adjusting for ME_{EXN}. Using the evaluation data subset, prediction potential of Eqs. (30)–(33) was also assessed (Table 13); slopes did not differ from one but intercepts differed from zero ($P < 0.05$).

4. Discussion

4.1. Methodology

Factorial approaches utilize assumptions to partition variables of interest, such as FCM_d, ME_{l-d} and NE_{l-d}. Hence, relationships between derived variables are influenced by specific assumptions employed. Nonetheless, factorial approaches with such databases are convenient for describing nutrient requirements of live-stock and have been effectively used for dairy cattle (Moe et al., 1972).

4.1.1. BW change

It was assumed that zero ADG equated to energy equilibrium. However, during early lactation loss in body fat often is accompanied by increases in gut size and body water content (Cowan et al., 1979, 1980,

Table 6

Observed versus predicted 4% fat-corrected milk (FCM, kg/day) for the evaluation data subset based on no-intercept versions of Eqs. (2) (P2), (3) (P3), (8) (P8) and (9) (P9) and ADG correction factors

Reference ^a	Source	Forage		Breed ^c	Phase ^d	Observed FCM	Predicted FCM ^e			
		Type ^b	%				P2	P3	P8	P9
788	Abijaoudé et al., 2000	AH + SBP	65	1	2	1.50	1.64	1.83	1.61	2.03
133	Badamana et al., 1990	Hay	57–61	2	1	2.64	2.09	2.06	1.93	2.17
292	Brun-Bellut et al., 1990	Dried beet pulp	10–15		1	2.39	2.23	2.62	2.27	2.62
292	Brun-Bellut et al., 1990	Dried beet pulp	10–15		2	2.01	2.00	2.14	1.83	2.09
495	Eik, 1991	Grass silage		15	1	2.26	2.29	2.09	1.84	2.09
485	El-Gallad et al., 1988	Berseem, clover hay, sweet sorghum	20–40	3	1	0.69	1.34	1.34	1.33	1.55
739	Goetsch et al., 2001	Cottonseed hull and ground AH	35–80	1	1	3.31	3.53	3.10	2.87	3.24
234	Hadjipanayiotou, 1988a	Barley straw and BH	24	5	2	1.92	2.08	2.13	1.79	2.11
153	Hadjipanayiotou and Hadjidemetriou, 1990	BH	25–65	5	1	1.77	1.86	1.65	1.50	1.73
735	Lu et al., 1987	Cottonseed hulls		1	2	2.68	2.53	2.94	2.76	3.05
842	Rapetti et al., 2001	Grass silage	55	2	1	4.31	4.00	4.81	4.17	4.93
842	Rapetti et al., 2001	Grass silage	55	2	2	3.48	4.06	4.86	4.16	4.95
842	Rapetti et al., 2001	Grass silage	55	2	3	2.28	2.74	2.85	2.36	2.92
707	Schmidely et al., 2002	Pelleted AH and SBP silage	70	1	1	4.73	3.01	3.55	3.08	3.65
707	Schmidely et al., 2002	Pelleted AH and SBP silage	70	1	2	4.43	4.48	4.30	3.87	4.41
707	Schmidely et al., 2002	Pelleted AH and SBP silage	70	1	3	3.90	3.77	4.24	3.75	4.37
Mean difference (Pred-Obs) ^f							-0.04	0.14	-0.20	0.23

^a Database reference number.

^b AH: alfalfa hay; BH: barley hay; SBP: sugar beet pulp.

^c 1: Alpine; 2: Saanen; 3: Nubian; 5: Damascus; 15: other dairy.

^d 1: 1–10 weeks; 2: 11–20 weeks; 3: >20 weeks.

^e Values were predicted from the no-intercept equations.

^f Predicted – observed.

Table 7

Observed versus predicted NE of lactation (NE_l, MJ/day) for the evaluation data subset based on the efficiency of use for lactation of dietary ME (k_{l-d}) from no-intercept versions of Eqs. (4) (P4), (5) (P5), (6) (P6), (7) (P7), (10) (P10), (11) (P11), (12) (P12) and (13) (P13) and ADG correction factors

Reference ^a	Source	Forage		Observed NE _l	Predicted NE _l							
		Type ^b	%		P4, $k_{l-d} =$ 0.62	P5, $k_{l-d} =$ 0.58	P6, $k_{l-d} =$ 0.67	P7, $k_{l-d} =$ 0.63	P10, $k_{l-d} =$ 0.59	P11, $k_{l-d} =$ 0.55	P12, $k_{l-d} =$ 0.63	P13, $k_{l-d} =$ 0.59
788	Abijaoudé et al., 2000	AH + SBP	65	4.62	4.81	5.76	6.23	5.64	5.08	6.39	4.98	6.26
133	Badamana et al., 1990	Hay	57–61	8.13	6.16	6.45	6.73	6.36	6.06	6.79	5.96	6.69
292	Brun-Bellut et al., 1990	Dried beet pulp	10–15	7.33	6.52	8.25	8.51	8.08	7.14	8.24	7.00	8.07
292	Brun-Bellut et al., 1990	Dried beet pulp	10–15	6.18	5.86	6.71	6.98	6.60	5.73	6.55	5.64	6.45
495	Eik, 1991	Grass silage		6.98	6.75	6.54	6.92	6.45	5.75	6.52	5.66	6.43
485	El-Gallad et al., 1988	Berseem, clover hay, sweet sorghum	20–40	2.12	3.94	4.21	4.49	4.15	4.16	4.86	4.10	4.79
739	Goetsch et al., 2001	Cottonseed hulls and ground AH	35–80	10.21	10.41	9.66	10.27	9.56	8.95	10.07	8.84	9.97
234	Hadjipanayiotou, 1988a	Barley straw and BH	24	5.91	6.11	6.68	7.07	6.58	5.62	6.61	5.53	6.50
153	Hadjipanayiotou and Hadjidemetriou, 1990	BH	25–65	5.44	5.53	5.18	5.51	5.08	4.73	5.44	4.63	5.34
735	Lu et al., 1987	Cottonseed hulls		8.25	7.40	9.27	9.39	9.09	8.67	9.58	8.50	9.39
842	Rapetti et al., 2001	Grass silage	55	13.26	11.70	15.20	15.80	14.85	13.13	15.54	12.85	15.18
842	Rapetti et al., 2001	Grass silage	55	10.72	11.88	15.38	16.04	15.02	13.12	15.64	12.83	15.29
842	Rapetti et al., 2001	Grass silage	55	7.05	8.01	8.95	9.68	8.80	7.39	9.16	7.26	9.01
707	Schmidely et al., 2002	Pelleted AH and SBP silage	70	14.58	8.81	11.22	11.71	10.97	9.70	11.51	9.49	11.26
707	Schmidely et al., 2002	Pelleted AH and SBP silage	70	13.65	13.13	13.46	14.21	13.30	12.09	13.77	11.93	13.60
707	Schmidely et al., 2002	Pelleted AH and SBP silage	70	12.02	11.03	13.36	13.93	13.10	11.79	13.73	11.56	13.47
Mean difference (Pred-Obs) ^c					0.52	0.61	1.06	0.45	−0.46	0.87	−0.61	0.70

^a Database reference number.

^b AH: alfalfa hay; BH: barley hay; SBP: sugar beet pulp.

^c Predicted – observed.

Table 8
Relationships between NE (kJ/day) and ME (kJ/day) for production and(or) maintenance^a

Equation	Dependent variable ^b	Independent variable ^c	Estimate ^d		R.M.S.E. ^e	Adjusted-R ²	k _p or k _{mp} ^f
			Intercept	Slope			
Method 1 ^g							
14	NE _p	ME _p	2134 (428.7)	0.48 (0.031)	2069.2	0.58	0.62 (0.012)
15		ME _{p-n}	2373 (421.5)	0.49 (0.033)	2091.5	0.57	0.66 (0.014)
16	NE _{mp}	ME _{mp}	2959 (623.3)	0.53 (0.027)	2105.0	0.70	0.66 (0.008)
17		ME _{mp-n}	3105 (625.5)	0.55 (0.028)	2127.3	0.70	0.68 (0.008)
18	NE _{p-d}	ME _{p-d}	1452 (553.6)	0.58 (0.042)	2001.0	0.63	0.68 (0.015)
19		ME _{p-d-n}	1736 (546.5)	0.59 (0.044)	2031.5	0.62	0.72 (0.016)
20	NE _{mp-d}	ME _{mp-d}	1550 (812.9)	0.62 (0.037)	2020.6	0.72	0.69 (0.009)
21		ME _{mp-d-n}	1691 (821.1)	0.64 (0.039)	2050.5	0.72	0.72 (0.009)
Method 2 ^g							
22	NE _p	ME _p	1865 (408.2)	0.50 (0.031)	2041.2	0.60	0.63 (0.012)
23		ME _{p-n}	2106 (402.5)	0.51 (0.032)	2067.3	0.60	0.66 (0.013)
24	NE _{mp}	ME _{mp}	2344 (574.2)	0.56 (0.025)	2094.5	0.74	0.66 (0.007)
25		ME _{mp-n}	2487 (577.5)	0.58 (0.026)	2120.7	0.74	0.69 (0.008)
26	NE _{p-d}	ME _{p-d}	1244 (542.6)	0.59 (0.042)	2001.2	0.64	0.68 (0.015)
27		ME _{p-d-n}	1542 (537.7)	0.61 (0.044)	2038.9	0.63	0.73 (0.016)
28	NE _{mp-d}	ME _{mp-d}	1038 (769.6)	0.64 (0.035)	2037.9	0.76	0.70 (0.009)
29		ME _{mp-d-n}	1181 (779.7)	0.59 (0.037)	2073.9	0.75	0.72 (0.009)

^a ME_p: ME available for production; ME_{p-d}: ME_p from the diet; ME_{mp}: ME for maintenance plus ME_p; ME_{mp-d}: ME_{mp} from the diet.

^b NE_p: NE for production; NE_{p-d}: NE_p from the diet; NE_{mp}: NE for maintenance plus NE_p; NE_{mp-d}: NE_{mp} from the diet.

^c ME_{p-n}, ME_{p-d-n}, ME_{mp-n} and ME_{mp-d-n} are, respectively, ME_p, ME_{p-d}, ME_{mp} and ME_{mp-d} adjusted for ME lost in excretion of excess urinary N.

^d Values in parentheses are S.E.

^e Root mean square error.

^f k_p and k_{mp} are slopes of no-intercept models, indicating efficiency of use of ME_p and ME_{mp}, respectively.

^g Method 1: use of assumptions of AFRC (1998) to predict ME for maintenance and activity; Method 2: use of estimates of ME for maintenance and activity from Luo et al. (2004b).

1981), whereas positive protein retention can coexist with negative energy balance (Haque et al., 1988). Any over-valuation of the energy value of BW change, which is quite possible as discussed below, would contribute to positive intercepts when NE_{l-d} was regressed against ME_{l-d}.

The energy concentration in live weight change from Eqs. (30)–(33) of 11.3 MJ ME/kg ADG is less than one-half of the assumed AFRC (1998) value of 23.9 MJ/kg, but nonetheless may be physiologically feasible. For example, ADG is least costly (e.g., 15.1 kJ/g ADG) if tissue accreted is mainly lean consisting of 75% water, particularly if part of the deposition cost is fueled by mobilized tissue energy. However, as alluded to later regarding the estimate of k_l, coefficients in multiple regressions have biological relevance in the context of use in the entire equation and not necessarily when viewed alone. To

more accurately describe nutrient requirements for milk production by goats, a greater knowledge of the composition of live weight loss and gain throughout lactation is needed (AFRC, 1998; Sutton and Alderman, 2000). The assumption of a constant energy concentration in live weight change may have contributed to change in the ratio of observed:predicted energy needs of the development data subset with increasing ADG, necessitating use of correction factors.

4.1.2. Genotype

Information available in the database did not permit an estimation of energy expended for the synthesis of fiber, which could have varied among genotypes. Also, with Method 1 it was assumed that ME_m was the same for all goats relative to BW^{0.75} and that ME was not influenced by level of milk production. However,

Table 9

Correction factors (CF3) for prediction of ME for production and(or) maintenance based on no-intercept versions of Eqs. (14)–(29)

Equation	Dependent variable	Independent variable ^a	Estimate ^b		R.M.S.E. ^b	Adjusted-R ²
			Intercept	Slope		
Method 1 ^c						
14	CF3	ADG	0.951 (0.0293)	−0.0007 (0.00022)	0.79	0.05
15	CF3	ADG	0.936 (0.0203)	−0.0003 (0.00022)	0.27	0.01
16	CF3	ADG	1.010 (0.0101)	−0.0008 (0.00011)	0.13	0.22
17	CF3	ADG	1.008 (0.0099)	−0.0008 (0.00011)	0.13	0.22
18	CF3	ADG	1.136 (0.0297)	−0.0018 (0.00033)	0.21	0.21
19	CF3	ADG	1.118 (0.0295)	−0.0017 (0.00032)	0.21	0.19
20	CF3	ADG	1.081 (0.0160)	−0.0011 (0.00017)	0.11	0.27
21	CF3	ADG	1.077 (0.0160)	−0.0011 (0.00017)	0.11	0.25
Method 2 ^c						
22	CF3	ADG	0.949 (0.0209)	−0.0006 (0.00023)	0.84	0.03
23	CF3	ADG	0.935 (0.0220)	−0.0002 (0.00024)	0.28	0.00
24	CF3	ADG	1.008 (0.0106)	−0.0007 (0.00012)	0.13	0.19
25	CF3	ADG	1.007 (0.0105)	−0.0007 (0.00012)	0.13	0.18
26	CF3	ADG	1.143 (0.0342)	−0.0018 (0.00038)	0.25	0.16
27	CF3	ADG	1.125 (0.0336)	−0.0016 (0.00037)	0.24	0.14
28	CF3	ADG	1.084 (0.0173)	−0.0011 (0.00019)	0.12	0.23
29	CF3	ADG	1.081 (0.0173)	−0.0011 (0.00017)	0.12	0.21

^a ADG is live weight gain (g/day).^b Root mean square error.^c Method 1: use of assumptions of AFRC (1998) to predict ME for maintenance and activity; Method 2: use of estimates of ME for maintenance and activity from Luo et al. (2004b).

activity and metabolic rates may differ among breeds and at different rates of milk production.

4.1.3. ME_m

Slopes of regressions forced to pass through the origin were employed because theoretically intercepts should not differ from zero. Also, for both ME_{l-d} and k_{l-d} , the slope, not the intercept, is of interest. It cannot be conclusively discerned why intercepts of Eqs. (4), (5), (10) and (11) differed from zero. However, one plausible explanation involves assumptions of ME_m . These equations address the increase in energy required for each unit increase in milk produced as well as an accompanying cost of maintaining mammary gland tissue. It is assumed that the latter change is linear with increasing ME_{l-d} , as is also presumed for milk production. However, since all treatment mean observations were for lactating animals, it is possible that the prediction of ME_{l-d} at zero milk production includes energy attributable to maintaining a functional mammary gland capable of milk secretion. In addition, different stages of preg-

nancy could impact energy requirements of lactating animals.

Data used in this study were derived from experiments with animals at various stages of lactation and geographical locations. Animals acclimated to environments with high temperatures have lower maintenance requirements than ones reared with lower temperatures (Tolkamp et al., 1994; NRC, 2000). Regarding stage of lactation, slightly more than one-half of the animals were in the early phase of lactation, when body energy reserves are often mobilized. Eik (1991) observed that body fat in does decreased until the 28th week of lactation. In early lactation, it is common for lactating does to have positive protein retention but negative energy balance (Haque et al., 1988; Aguilera et al., 1990; Prieto et al., 1990; Sastradipradja et al., 1994), which can be explained by fat mobilization and a relatively high and increasing proportion of lean (protein) tissue in the body. Hence, because of more energy required to maintain protein than fat (Webster, 1980), relative to $BW^{0.75}$ the maintenance energy requirement may be higher in early

Table 10

Regressions of observed against predicted ME (P-ME; kJ/day) with the evaluation data subset for production and(or) maintenance based on no-intercept versions of Eqs. (14)–(29) and ADG correction factors

Equation	Intercept		P-ME		R.M.S.E. ^a	Adjusted-R ²	Significance (P<) ^b	
	Estimate	S.E.	Estimate	S.E.			Intercept	Slope
Method 1 ^c								
14	–351	708.3	0.99	0.049	5534.8	0.85	0.62	0.89
15	–367	824.7	0.95	0.055	6281.1	0.80	0.66	0.37
16	322	1185.3	0.94	0.048	6254.3	0.84	0.79	0.23
17	651	1225.7	0.94	0.050	6508.4	0.83	0.60	0.22
18	1157	1178.0	0.87	0.083	6778.8	0.73	0.33	0.13
19	1172	1207.1	0.89	0.087	6909.6	0.72	0.34	0.23
20	983	1935.2	0.94	0.81	6866.8	0.77	0.61	0.46
21	1795	1941.2	0.92	0.82	7079.6	0.75	0.36	0.32
Method 2 ^c								
22	–417	711.6	1.01	0.050	5535.8	0.85	0.56	0.85
23	–368	825.0	0.96	0.056	6282.9	0.80	0.65	0.48
24	164	1172.9	0.96	0.048	6163.9	0.85	0.88	0.35
25	497	1214.6	0.95	0.050	6424.0	0.83	0.68	0.33
26	1124	1170.6	0.87	0.082	6733.7	0.74	0.34	0.13
27	1139	1200.0	0.87	0.086	6866.0	0.73	0.35	0.22
28	953	1925.8	0.94	0.081	6834.0	0.77	0.62	0.47
29	1772	1932.9	0.92	0.082	7050.8	0.76	0.37	0.32

^a Root mean square error.

^b Significance of difference of the intercept from 0 and slope from 1.

^c Method 1: use of assumptions of AFRC (1998) to predict ME for maintenance and activity; Method 2: use of estimates of ME for maintenance and activity from Luo et al. (2004b).

versus late lactation. In accordance, Emmans (1997) suggested that for a given genotype, maintenance heat production is directly proportional to body protein mass. In addition, energy required for repair of reproductive tissue following parturition could elevate the ME_m requirement in early lactation. Moreover, Moe et al. (1972) noted that factors such as pregnancy, nutrient imbalances, disease, tissue energy gain, environmental stress and exercise tend to increase energy expended for maintenance. Consequently, applying a single ME_m throughout lactation could result in underestimation of energy needs for milk synthesis early in lactation and overestimation later.

Requirement expressions developed by Luo et al. (2004b) suggested that dairy breeds could have higher ME_m than other breeds of goats. Relative to Method 1 (based on ME_m proposed by AFRC, 1998), k_{1-d} for Method 2 (based on ME_m from Luo et al., 2004b) were slightly lower and ME_{1-d} required per kg FCM_d were greater. Nonetheless, Method 2 had similar if not slightly higher adjusted-R² of predictions of FCM compared with Method 1.

4.2. Effect of dietary CP

In most reports used in the database, goats had unrestricted access to both diet and water. As is typical of diets consumed by lactating goats throughout the year and in a wide array of production systems, the dietary CP concentration in this database was variable (i.e., 10–20%). As noted previously, use of dietary CP concentration higher than necessary increases loss of energy in excretion of excess N. Energy loss in terms of FCM for diets ranging in CP concentration from 10 to 20% calculate to be from 44 to 259 and 54 to 382 g/day for goats weighing 40 and 60 kg, respectively. Hence, benefits of increasing the CP content of the diet to intake, milk yield and milk protein content, which sometimes (Broster and Oldham, 1981; Badamana et al., 1990; Pailan and Kaur, 1996) but not always have been observed (Sahlu et al., 1993; Brun-Bellut et al., 1990), need to be balanced against the associated trade-off in order to select the ideal level for economical milk production.

Table 11

Observed versus predicted ME_p , ME_{p-d} and ME_{mp} (MJ/day) with the evaluation data subset based on k_p , k_{p-d} and k_{mp} , respectively, from no-intercept versions of Eqs. (14)–(29) and ADG correction factors^a

Reference ^b	Source	Phase ^c	ME_p			ME_{mp}			ME_{p-d}			ME_{mp-d}		
			Obs ^d	Pred ^d	Pred-N ^d	Obs ^d	Pred ^d	Pred-N ^d	Obs ^d	Pred ^d	Pred-N ^d	Obs ^d	Pred ^d	Pred-N ^d
Method 1 ^e														
788	Abijaoudé et al., 2000	2	10.2	9.7	11.2	21.6	21.1	21.3	10.2	9.7	10.0	21.6	20.9	21.1
133	Badamana et al., 1990 ^f	1	9.6	12.7	12.7	21.4	25.3	24.7	9.0			21.4		
292	Brun-Bellut et al., 1990	1	13.4	13.7	14.9	22.4	22.7	22.3	13.4	13.6	13.1	22.4	22.5	22.1
292	Brun-Bellut et al., 1990	2	10.2	10.2	10.7	18.4	19.1	18.7	10.2	10.8	10.4	18.4	19.3	19.0
495	Eik, 1991	1	10.7	11.5	11.7	18.9	20.9	20.7	9.4	12.6	12.2	18.9	21.6	21.4
485	El-Gallad et al., 1988	1	6.2	3.3	3.7	13.0	10.2	10.3	6.1	4.1	4.2	13.0	10.4	10.5
739	Goetsch et al., 2001	1	16.3	16.9	16.9	26.5	28.6	28.4	14.2	17.4	17.1	26.5	29.6	29.4
234	Hadjipanayiotou, 1988a	2	10.5	10.0	10.8	21.1	21.6	21.5	10.2	10.3	10.2	21.1	21.9	21.8
153	Hadjipanayiotou and Hadjidemetriou, 1990	1	8.0	8.7	9.0	18.7	21.0	20.9	6.1	10.6	10.7	18.7	21.8	21.7
735	Lu et al., 1987	2	14.3	14.4	15.1	24.3	24.2	23.3	14.3	14.7	13.7	24.3	24.2	23.3
842	Rapetti et al., 2001	1	22.3	22.6	25.7	31.2	31.4	31.4	22.3	21.8	21.6	31.2	30.9	31.0
842	Rapetti et al., 2001	2	22.5	19.1	21.9	32.1	28.7	29.0	22.5	18.4	18.5	32.1	28.3	28.6
842	Rapetti et al., 2001	3	13.5	11.8	13.5	23.8	23.0	23.6	13.5	12.5	13.1	23.8	23.2	23.8
707	Schmidely et al., 2002	1	17.6	24.4	27.4	28.5	35.0	34.7	17.6	23.6	23.0	28.5	34.4	34.2
707	Schmidely et al., 2002	2	20.7	21.4	21.8	31.5	33.5	33.3	19.9	24.0	24.2	31.5	34.4	34.2
707	Schmidely et al., 2002	3	20.0	20.1	22.1	31.0	31.1	30.9	20.0	20.1	19.8	31.0	31.0	30.8
Mean				0.3	1.5		0.8	0.7		1.3	1.1		0.9	0.8
difference (Pred-Obs) ^g														
Method 2 ^e														
788	Abijaoudé et al., 2000	2	10.2	9.7	11.1	21.6	21.0	21.2	10.2	9.7	10.0	21.6	24.2	24.0
133	Badamana et al., 1990 ^f	1	9.6	12.5	12.6	21.4	25.1	24.5	9.0			21.4		
292	Brun-Bellut et al., 1990	1	13.4	13.6	14.8	22.4	22.6	22.2	13.4	13.7	13.2	22.4	24.5	23.8
292	Brun-Bellut et al., 1990	2	10.2	10.1	10.6	18.4	19.0	18.6	10.2	10.8	10.4	18.4	19.6	19.1
495	Eik, 1991	1	10.7	11.3	11.6	18.9	20.8	20.6	9.4	12.6	12.2	18.9	21.7	21.2
485	El-Gallad et al., 1988	1	6.2	3.3	3.7	13.0	10.1	10.2	6.1	4.1	4.2	13.0	10.9	10.9
739	Goetsch et al., 2001	1	16.3	16.6	16.8	26.5	28.3	28.1	14.2	17.5	17.2	26.5	27.2	26.9
234	Hadjipanayiotou, 1988a	2	10.5	9.9	10.7	21.1	21.5	21.4	10.2	10.3	10.2	21.1	23.4	23.0
153	Hadjipanayiotou and Hadjidemetriou, 1990	1	8.0	8.5	8.9	18.7	20.8	20.7	6.1	10.6	10.6	18.7	21.3	21.0
735	Lu et al., 1987	2	14.3	14.4	14.9	24.3	24.0	23.2	14.3	14.7	13.8	24.3	25.7	24.5
842	Rapetti et al., 2001	1	22.3	22.6	25.4	31.2	31.3	31.3	22.3	21.9	21.7	31.2	34.7	34.3
842	Rapetti et al., 2001	2	22.5	19.1	21.7	32.1	28.6	28.9	22.5	18.5	18.6	32.1	31.7	31.6
842	Rapetti et al., 2001	3	13.5	11.7	13.4	23.8	22.8	23.4	13.5	12.5	13.1	23.8	23.7	24.1
707	Schmidely et al., 2002	1	17.6	24.4	27.1	28.5	34.9	34.5	17.6	23.7	23.1	28.5	38.6	37.9
707	Schmidely et al., 2002	2	20.7	21.1	21.6	31.5	33.2	33.0	19.9	24.0	24.2	31.5	32.9	32.4
707	Schmidely et al., 2002	3	20.0	20.0	21.8	31.0	30.9	30.7	20.0	20.2	19.8	31.0	33.3	32.8
Mean				0.2	1.3		0.7	0.5		1.0	0.8		2.0	1.6
difference (Pred-Obs) ^g														

^a ME_p : ME available for production; ME_{p-d} : ME_p from the diet; ME_{mp} : ME for maintenance plus ME_p ; k_p : efficiency of use of ME_p ; k_{p-d} : efficiency of use of ME_{p-d} ; k_{mp} : efficiency of use of ME_{mp} .

^b Database reference number.

^c 1: 1 to 10 weeks; 2: 11 to 20 weeks; 3: > 20 weeks.

^d Obs: observed; Pred: predicted; Pred-N: predicted with an adjustment for energy lost in excretion of excess urinary N.

^e Method 1: use of assumptions of AFRC (1998) to predict ME for maintenance and activity; Method 2: use of estimates of ME for maintenance and activity from Luo et al. (2004b).

^f Predicted ME_{p-d} and ME_{mp} are not shown because of BW loss.

^g Predicted – observed.

Table 12

Regressions of ME intake (kJ/kg BW^{0.75}) against ADG (g/kg BW^{0.75}), 4% fat-corrected milk (FCM; kg/kg BW^{0.75}) and NE of lactation (NE_l, kJ/kg BW^{0.75})

Equation	Intercept		ADG		FCM		NE _l		R.M.S.E. ^a	Adjusted-R ²	k _l ^b
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.			
Without adjusting for energy lost in excretion of excess urinary N											
30	583	28.6	11.3	2.20	4384	222.0			439.6	0.69	
31	583	28.6	11.3	2.20			1.42	0.072	439.7	0.69	0.70
After adjusting for energy lost in excretion of excess urinary N											
32	574	28.5	11.3	2.20	4298	221.3			438.4	0.69	
33	574	28.5	11.3	2.19			1.39	0.071	438.3	0.69	0.72

^a Root mean square error.

^b Efficiency of ME use for lactation.

Table 13

Regressions of observed against predicted 4% fat-corrected milk (P-FCM, kg/day) or NE for lactation (P-NE_l, kJ/day) based on no-intercept versions of Eqs. (30)–(33)

Equation	Intercept		P-FCM		P-NE _l		R.M.S.E. ^a	Adjusted-R ²	Significance (P<) ^b	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.			Intercept	Slope
Without adjusting for energy lost in excretion of excess urinary N										
30	0.28	0.151	0.95	0.057			1.542	0.78	0.067	0.37
31	865	465.2			0.95	0.057	4751.8	0.78	0.067	0.34
After adjusting for energy lost in excretion of excess urinary N										
32	0.31	0.151	0.94	0.057			1.556	0.77	0.041	0.27
33	964	464.4			0.93	0.057	4791.6	0.77	0.041	0.24

^a Root mean square error.

^b Significance of difference of the intercept from 0 and slope from 1.

4.3. ME_{l-d}/FCM_d and NE_{l-d} estimates

Based on scatter plots of residuals from no-intercept versions of equations with the development data subset, energy requirements seem to have been adequately described. Furthermore, except for Eq. (6) the finding that both intercepts and slopes of regressions of observed values of the evaluation data subset against those predicted did not differ from zero and one, respectively, lends further validity to the factorially derived requirement expressions. There were no particular equations that explained considerably greater variability in observed FCM or NE_l than other equations. However, when there is considerable variance associated with the independent variable, the regression coefficient is biased low; therefore, errors in intercepts and slopes are minimized when the variable with the least variability is used as the X or independent vari-

able (Daniel and Wood, 1980; Johnson et al., 1998). In this study, milk yield was directly determined for all observations, but ME concentration in the diet was not in most cases. This implies greater variation in ME_{l-d} than in FCM_d and NE_{l-d}, suggesting use of FCM_d and NE_{l-d} as independent variables such as in Eqs. (2), (3), (6)–(8), (9), (12) and (13). As noted previously, Eqs. (2), (3), (8) and (9) to predict FCM are comparable to Eqs. (6), (7), (12) and (13) to predict NE_l, respectively, with the same explained variability and k_{l-d}. For simplicity and since adjustment for ME_{ExN} did not improve accuracy of prediction, employment of Eqs. (3) or (9), associated ADG correction factors and the factorial approach assumptions might be preferable for describing energy requirements for lactating goats.

Although use of k_l from multiple regression analyses (Eqs. (30)–(33)) accounted for 76–77% of vari-

ability in milk yield and slopes of regressions of observed against predicted values of the evaluation data subset that did not differ from one, intercepts differed from zero, implying that the multiple regression approach was inferior to factorial methods. This could be because the objective of the least square algorithm is to minimize variance estimates, which is independent of biological feasibility of k_1 . However, predictions of FCM in the evaluation data subset based on k_p , k_{mp} , k_{p-d} and k_{mp-d} accounted for 72–85% of variation, and intercepts and slopes of regressions of observed against predicted values for the evaluation data subset did not differ from zero and one, respectively, suggesting utility comparable to equations from the factorial approach. Nonetheless, since efficiency of ME use varies considerably with function (i.e., mobilized tissue for lactation and dietary energy for tissue gain and lactation), a factorial approach would seem most appropriate to adequately address energy needs throughout a lactation cycle and with various diet qualities and levels of intake.

There is curvilinearity in the relationship between dietary ME concentration and k_1 or NE_1/ME_1 in other energy systems such as NRC (1989). However, in the present study quadratic effects were checked and found to be nonsignificant. In accordance, NE_{1-d} was not correlated with ME concentration in the diet ($r = -0.14$; $P > 0.10$). This may in part relate to inclusion in the database of goats not highly selected for milk production, resulting in a large range in milk yield (0.08–5.46 kg/day) compared with data used in other systems (e.g., NRC, 1989).

Reported estimates of k_1 for lactating goats have been quite variable and include 0.69–0.82 (Badamana et al., 1990), 0.58–0.89 (Sanz Sampelayo et al., 1998), 0.667 (Aguilera et al., 1990), 0.69–0.70 (Hadjipanayiotou, 1988a) and 0.62 (Economides, 1986). Our factorial approach k_{1-d} estimates based on no-intercept regressions of NE_{1-d} against ME_{1-d} of 0.62 and 0.58 for Method 1 and 0.59 and 0.55 for Method 2 with and without adjustment for ME_{EXN} , respectively, are within the range of 0.55–0.66 noted for goats and other ruminants in other requirement reports (ARC, 1980; AFRC, 1998). Estimates derived indirectly from regression of ME_{1-d} against FCM_d or NE_{1-d} were slightly greater than from regression of NE_{1-d} against ME_{1-d} , and were in closer agreement with previous values noted for goats. Conversely,

those based on multiple regression analysis in which ME_m was not assumed (Eqs. (9) and (11)) of 0.70 and 0.72 were slightly greater.

Estimates of ME_{1-d}/FCM_d based on no-intercept regressions in the present study were 4598 and 4937 kJ/kg FCM_d (Method 1) or 4882 and 5224 kJ/kg FCM_d (Method 2) with and without adjustment for ME_{EXN} , whereas those from multiple regression analysis were 4298 and 4384 kJ/kg FCM, respectively (Eqs. (30) and (32), respectively). Previous estimates of ME_1/FCM for goats are similar to ones of the present study, including 4200–4900 (Aguilera et al., 1984, 1990) and 4712–4838 kJ/kg FCM (Hadjipanayiotou, 1988a), which were derived using factorial approaches without adjustment for ME_{EXN} .

5. Summary and conclusions

With no-intercept regressions and employing ME_m proposed by AFRC (1998), dietary ME required for milk production was 4937 and 4598 kJ/kg FCM without and after correcting for ME_{EXN} , respectively. With the ME_m determined from estimates of Luo et al. (2004b), dietary ME required for milk production was 5224 and 4882 kJ/kg FCM without and after correcting for ME_{EXN} , respectively. Prediction accuracy was similar between methods and improved slightly by correction for ADG. These estimates yielded predictions closely matching observed responses in milk yield and energy with an evaluation data subset and, thus, should have value for describing energy requirements of lactating goats, particularly considering the large size of the database used in this study. However, for proper employment of these requirement expressions, the same approaches for partitioning ME_{1-d} and FCM_d is necessary.

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