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Prediction of metabolizable energy requirements for maintenance and gain of preweaning, growing and mature goats

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Abstract

Databases were constructed to determine ME requirements for maintenance (ME_m) and BW gain (ME_g) of preweaning, growing and mature goats by regressing ME intake (MEI) against ADG. Goats were categorized as dairy, meat ($\geq$ 50% Boer) or indigenous biotypes. The preweaning database included 98 treatment means representing 1016 goats and the growing goat database consisted of 333 treatment means. Because of differences among biotypes of growing goats in intercepts and slopes ($P < 0.05$), separate regressions were performed. The meat subset included 60 observations from 11 publications, representing 548 goats; the dairy subset had 116 observations from 25 publications with 1851 goats; and the indigenous subset consisted of 157 observations from 34 publications and 1024 goats. Dairy and indigenous subsets were randomly split into independent sets for equation development and evaluation. The mature goat database included 69 treatment means from 23 publications and represented 495 goats. Small numbers of observations removed after initial regressions to improve fit did not markedly alter intercepts or slopes. Equations were as follows: preweaning: MEI (kJ/kg $BW^{0.75}$) = 484.6 (S.E. = 61.46) + (13.37 [S.E. = 1.95] × ADG [g/kg $BW^{0.75}$]) ($n = 61$; $R^2 = 0.44$); meat: MEI (kJ/kg $BW^{0.75}$) = 457.0 (S.E. = 22.30) + (25.23 [S.E. = 1.74] × ADG [g/kg $BW^{0.75}$]) ($n = 57$; $R^2 = 0.79$); dairy: MEI (kJ/kg $BW^{0.75}$) = 573.7 (S.E. = 46.20) + (23.56 [S.E. = 3.10] × ADG [g/kg $BW^{0.75}$]) ($n = 56$; $R^2 = 0.52$); indigenous: MEI (kJ/kg $BW^{0.75}$) = 500.0 (S.E. = 11.94) + (18.59 [S.E. = 1.64] × ADG [g/kg $BW^{0.75}$]) ($n = 76$; $R^2 = 0.63$); and mature: MEI (kJ/kg $BW^{0.75}$) = 462.2 (S.E. = 24.95) + (28.52 (S.E. = 5.05) × ADG [g/kg $BW^{0.75}$]) [$n = 69$; $R^2 = 0.32$]. Intercepts and slopes from regressions of observed against predicted MEI with evaluation data sets, based on equations for preweaning and growing dairy and indigenous goats, were not different from 0 to 1, respectively. When final equations for the different growing goat biotypes were tested, the intercept for dairy goats differed ($P < 0.05$) from that of meat and indigenous goats, and the slope for indigenous goats tended ($P = 0.16$) to differ from that of meat and dairy goats. Therefore, the following dummy variable equation was obtained ($I_1 = 1$ for dairy and 0 for others; $I_2 = 1$ for indigenous and 0 for others): MEI (kJ/kg $BW^{0.75}$) = 488.5 (S.E. = 14.4) + (91.5 (S.E. = 18.69) × I_1)

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$+ (23.09\ (\text{S.E.} = 1.24) \times \text{ADG}\ [\text{g/kg BW}^{0.75}]) - (3.28\ (\text{S.E.} = 1.98) \times \text{ADG}\ [\text{g/kg BW}^{0.75}] \times I_2)$ [$n = 189$; $R^2 = 0.74$]. In summary, based on treatment mean observations from available publications and regression of MEI against ADG, ME_m was 485, 489, 580, 489 and 462 kJ/kg $\text{BW}^{0.75}$, and ME_g was 13.4, 23.1, 23.1, 19.8 and 28.5 kJ/g ADG for preweaning, growing meat, growing dairy, growing indigenous and mature goats, respectively.

Keywords: Goat; Energy requirement; Maintenance; Growth

1. Introduction

Respiration calorimetry, both in fed and fasted states, and comparative slaughter have frequently been used to assess the energy requirements of livestock. These methods have high equipment, facility, labor and(or) analytical costs, and respiration calorimetry requires unnatural conditions for measurement. For comparative slaughter, a constant rate of energy retention between slaughter points is assumed. Furthermore, energy requirement estimates from these methods can differ because of factors including length of the measurement period and potential interactions among factors such as dietary characteristics, level of feed intake, stress and environmental conditions (Geay, 1984; Beever et al., 1988; Unsworth et al., 1991).

Another common method of assessing energy requirements is use of BW change or gain as an indirect measure of energy retention, with regression analysis (Onwuka and Akinsoyinu, 1989; Zemmelink et al., 1991; Pralomkarn et al., 1995; Early et al., 2001). Disadvantages of this method include the assumption of a constant energy concentration in BW gain or loss (McDonald et al., 1977) and the possible effects of differences in gut digesta fill on BW measurements (Rohr and Daenicke, 1984). Nonetheless, the accuracy of BW measurement can be high, facilitating use of ADG as an independent variable. Another advantage of using BW gain is that measurements can be obtained under fairly typical production conditions (e.g., ad libitum feed intake), which also might minimize variability in energy concentration in tissue gain (Lofgreen, 1965) and gut digesta fill (Van Soest, 1994). Furthermore, Kirkpatrick et al. (1997) suggested that maintenance energy requirements of ARC (1980), AFRC (1993) and AFRC (1998) derived from fasted animals are likely underestimated because of differences in metabolic activity of tissues between fed and fasted states, specifically greater visceral organ energy use in full-fed versus fasted animals. One additional consideration for use of BW change and regression analyses to determine energy and nutrient requirements is that many publications are available compared with calorimetry and comparative slaughter experiments, thereby allowing the evaluation of such factors as animal breed or biotype and age. Breed and age of other ruminant species have been shown to affect energy requirements (Webster et al., 1974; Tyrrell and Moe, 1980; Moe, 1981; Kirkland and Gordon, 1999).

The ME requirement for maintenance (ME_m) of goats from NRC (1981) of 424.2 kJ/kg $\text{BW}^{0.75}$ was obtained by averaging values in 10 publications from 1950 to 1980. Similarly, the NRC (1981) ME requirement for growth (ME_g; 30.3 kJ/g ADG, with a coefficient of variation of over 30%) was based on three experimental values, published in 1967, 1974 and 1979. AFRC (1998) presented a ME_m estimate of 438 kJ/kg $\text{BW}^{0.75}$, which was derived by averaging values from 17 publications from 1960 to 1990; values were obtained from both estimates of fasting heat production and efficiency of ME use for maintenance derived from metabolizability of the diet and feeding trials where ME intake and retained energy or BW gain were measured. Because such recommendations are not based on a large amount of data and because ME_m might vary among different ages and biotypes of goats, the current study was performed to use available research publications to estimate ME_m and ME_g of preweaning, growing and mature goats classed as dairy, meat ($\geq$ 50% Boer) or indigenous biotypes.

2. Materials and methods

2.1. ME intake derivation

ME intake (MEI) was either reported or calculated from information presented in publications used in this study. There were three origins of MEI: (1) reported in the publication based on a determination of digestibility or metabolizability; (2) reported in the publication by original author(s) based on calculation from dietary proportions of individual feedstuffs and their ME concentrations; (3) calculated for the present study based on dietary proportions of individual feedstuffs and their ME concentrations first from NRC (1981), and then if not available from NRC (1984, 1985). Of the 512 treatment mean observations used in this study, 189, 160 and 163 were obtained via methods 1, 2 and 3, respectively.

2.2. *Preweaning database*

This database was compiled from 15 publications (Table 1; Appendix A) involving 98 treatment means from a total of 1016 preweaning goats. For use in this study, publications either reported or had information necessary to calculate ADG and mean BW. Experiments were conducted under confined conditions, with kids receiving goat milk, cow milk or milk replacer, plus in some instances limited amounts of dry feeds. The length of experiments ranged from 21 to 106 days, except for one experiment lasting 7 days with eight observations. Deletion of these eight treatment means did not affect the intercept ($P = 0.98$) or slope ($P = 0.99$) of equations from regressions of MEI against ADG; thus, all observations were used in the regression analysis. Because of the large number of genotypes in the database and in some cases fairly general descriptions, it was not possible to investigate potential genotype differences. Rather, goats were categorized into different biotypes regarding previous degree of selection for specific production characteristics that conceivably could impact nutritional needs. There were seven breeds and three crossbreeds, categorized as: dairy (e.g., Saanen, Alpine, Damascus, Norwegian, Swedish Landrace and dairy crossbred), meat ($\geq 50\%$ Boer) and indigenous (neither dairy nor meat; not including Angora). However, the great majority (i.e., 83) of treatment mean observations was for dairy goats.

Using PROC GLM of SAS (1990), differences among biotypes in intercepts and slopes of regressions of MEI against ADG were tested by analysis of covariance (Snedecor and Cochran, 1978). Differences were not significant ($P = 0.87$); therefore, data for the various biotypes were combined.

In order to evaluate regression models, databases often are split into independent subsets for equation development and evaluation according to characteristics of the database. It is desirable to split by publication or reference (Moore et al., 1999); however, because of the relatively small number of references in the preweaning database, it was not possible to split by reference into homogeneous subsets. Therefore, treatment mean observations were used as the basis of splitting by assigning each a random number to separate into development and evaluation subsets (Montgomery and Peck, 1982). Data in the two subsets were made as homogeneous as possible for the most important variables (i.e., MEI, ADG and mean BW) by exchange of a small number of observations. Mean, minimum and maximum values for most variables were similar (Table 2), although the range in MEI of the development subset was slightly greater than of the evaluation subset. MEI was regressed against ADG using PROC REG of SAS (1990), with both variables scaled by $BW^{0.75}$ to account for differences among breeds and biotypes caused by differences in metabolic size (Pralomkarn et al., 1995). With this and all other data sets, quadratic and cubic effects of ADG were checked

Table 1
Summary of database for prediction of ME requirements for maintenance and gain of preweaning goats

Variable	*n*	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	98	7.73	3.091	2.28	21.80
DM intake (kg/day)	98	0.213	0.9608	0.065	0.555
CP (% DM)	95	26.1	7.80	18.7	55.0
Forage (%)	98	1.19	3.115	0	19.90
ME intake (MJ/day)	98	4.13	1.675	1.33	9.20
ME intake (MJ/($BW^{0.75}$ × day))	98	0.890	0.2059	0.372	1.467
BW gain (g/day)	98	139	63.6	–71	272
BW gain (g/($BW^{0.75}$ × day))	98	30.0	9.52	–13.1	48.3

Table 2
Summary of development and evaluation database subsets for prediction of ME requirements for maintenance and gain of preweaning goats

Variable	Development set					Evaluation set				
	n	Mean	S.D.	Minimum	Maximum	*n*	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	62	7.88	3.342	2.28	21.80	36	7.48	2.628	2.43	12.90
DM intake (kg/day)	62	0.217	0.1011	0.065	0.555	36	0.207	0.0878	0.069	0.455
CP (% DM)	60	26.1	8.10	18.7	55.0	35	26.1	7.38	19.3	55.0
Forage (% of DM)	62	1.27	3.395	0	19.90	36	1.06	2.602	0	10.70
ME intake										
MJ/day	62	4.19	1.032	1.75	6.90	36	4.01	0.826	2.44	5.99
MJ/(day × kg BW$^{0.75}$)	62	0.891	0.2200	0.372	1.467	36	0.887	0.1826	0.538	1.324
ADG (g)	62	138	65.1	–71	248	36	140	61.8	33	272
ADG (g/kg BW$^{0.75}$)	62	29.8	10.32	–13.1	48.3	36	30.3	8.11	9.1	47.3

and found to be nonsignificant ($P \geq 0.38$). For this and other regressions, the residual (difference between actual and predicted values) for each observation was compared with various multiples of the residual SD (rS.D.). Observations with differences greater than selected rS.D. were removed and changes in regression R^2 and root mean square error (RMSE) were viewed. The rS.D. used to exclude observations was chosen on the basis of a moderate to appreciable increase in explained variability, while retaining the maximum number of observations. Observations removed from the subset were examined in detail for each computation (Chatterjee et al., 2000). Figures for this and other data sets show removed observations as well as regression lines before and after removal. The modified equation derived from the development subset of the preweaning database was used to predict MEI in the evaluation subset. Observed values were regressed on predictions to determine whether the intercept and slope differed from 0 and 1, respectively.

2.3. Growing database

This database included 333 treatment means of growing goats (postweaning up to 18 months of age, not lactating or pregnant, including male, female and wether goats) from 70 publications (Appendix B). Experiment length ranged from 21 to 294 days. Because the database was composed of the same three goat biotypes noted before, differences in intercepts and slopes from regressions MEI against ADG for each biotype were tested using methods described earlier for the preweaning database. In contrast to the preweaning database, there were differences in intercepts ($P < 0.01$) and slopes ($P < 0.05$); hence, separate regressions were computed for the three biotypes.

The subset for meat goats included 60 treatment means from eight publications and three reports of meat goat buck performance tests, representing a total of 548 goats (Table 3). Because of the limited number of treatment mean observations, the subset could not be split into development and evaluation components, and all data were used for regression of MEI against ADG.

The subset for dairy goats included 116 treatment means from 25 publications representing 1851 goats. These data are summarized in Table 3. Because of the size of this subset, it was split using publication or reference as the basis into a development and evaluation sub-subsets. A summary of variables in both sub-subsets is shown in Table 4. Equation development and testing with the evaluation sub-subset were conducted as described earlier for the preweaning database.

The subset for indigenous goats included 157 treatment means from 34 publications representing a total of 1024 goats. A summary of variables in this subset is given in Table 3. Development and evaluation sub-subsets were constructed as described for the dairy sub-subset, and a summary of variables is shown in Table 5. Equation development and testing with the evaluation sub-subset were described previously for other databases.

2.4. Mature database

The mature goat database initially included 81 treatment means of mature goats (over 18 months of age) from 23 publications (Appendix C) in which BW change was reported. However, so that energy rather than protein limited BW gain, treatment means with a ratio of MEI:CP intake greater than 106 kJ/g of CP were considered protein deficient (Moore et al., 1999) and removed. The resulting database included 69 treatment means representing 495 goats of 14 identified breeds and one crossbreed (Table 6). The length of experiments ranged from 20 to 365 days, except for three treatment means from a 12-day experiment. Deletion of these three treatment means did not affect the intercept ($P = 0.93$) or slope ($P = 0.97$) of equations from regressions of MEI against ADG; thus, all observations were used in the regression analysis. This database was not split because of a limited number of observations. In addition, there were no meat goat biotype observations. Intercepts and slopes of regressions of MEI against BW change for dairy and indigenous goats did not differ ($P = 0.65$); therefore, data were combined for further regressions of MEI against ADG as noted before for the preweaning database.

Table 3
Summary of database subsets for prediction of ME requirements for maintenance and gain of growing goats

Variable	Meat goats[a]					Dairy goats[b]					Indigenous goats[c]				
	n	Mean	S.D.	Minimum	Maximum	n	Mean	S.D.	Minimum	Maximum	n	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	60	32.3	8.42	13.1	52.1	116	23.0	8.00	12.8	68.0	157	16.6	7.10	6.4	43.0
DM intake (kg/day)	60	1.02	0.373	0.47	1.93	116	0.830	0.2643	0.379	1.632	157	0.507	0.1856	0.188	0.931
CP (% of DM)	60	17.0	3.09	10.2	25.0	116	15.9	3.77	8.0	29.2	152	15.0	4.24	5.9	27.8
Forage (% of DM)	60	46.5	22.24	0	74.0	116	31.5	31.95	0	100.0	152	50.6	30.13	0	100.0
MEI[d] (MJ/day)	60	1.03	2.925	5.49	17.65	116	9.35	3.528	3.29	16.97	157	4.81	1.841	1.99	9.22
MEI (MJ/(day × kg $BW^{0.75}$))	60	0.764	0.1451	0.516	1.116	116	0.884	0.2281	0.475	1.428	157	0.588	0.1210	0.319	0.901
ADG (g)	60	158	70.9	67	290	116	138	74.7	−107	294	157	47.5	35.77	−84.0	177.2
ADG (g/kg $BW^{0.75}$)	60	11.8	4.96	6.1	22.9	116	13.5	6.67	−7.7	26.6	157	5.98	4.266	−8.51	21.42

[a] Meat: $ 50% Boer.

[b] Dairy: Saanen, Alpine, Damascus, Norwegian, Swedish Landrace and dairy crossbreed.

[c] Indigenous: neither Meat nor Dairy, not including Angora.

[d] ME intake.

3. Results

3.1. Preweaning database

Regressing MEI (kJ/kg $BW^{0.75}$) against ADG (g/kg $BW^{0.75}$) yielded the following equation:

$$\mathrm{MEI} = 477.7(\mathrm{S.E.} = 65.8) + (13.87(\mathrm{S.E.} = 2.09) \times \mathrm{ADG}), \quad n = 62,\ R^2 = 0.42 \qquad (1)$$

To improve model fit, the plot of residuals against predicted MEI was examined to identify observations with large residuals. There was one residual greater than 2 rS.D., which was removed, resulting in the following equation:

$$\mathrm{MEI} = 484.6(\mathrm{S.E.} = 61.5) + (13.37(\mathrm{S.E.} = 1.95) \times \mathrm{ADG}), \quad n = 61,\ R^2 = 0.44 \qquad (2)$$

Regression lines of Eqs. (1) and (2) are presented in Fig. 1. Eq. (2) had a smaller RMSE (156 versus 168) and S.E. of both the intercept and slope and was

Table 4
Summary of development and evaluation database sub-subsets for prediction of ME requirements for maintenance and gain of growing dairy goats

Variable	Development					Evaluation				
	n	Mean	S.D.	Minimum	Maximum	*n*	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	63	23.8	8.53	12.8	52.2	53	22.1	7.30	13.0	68.0
DM intake (kg/day)	63	0.848	0.2898	0.379	1.410	53	0.808	0.2312	0.421	1.632
CP (% of DM)	63	16.0	3.32	8.0	20.0	53	15.7	4.26	8.0	29.2
Forage (% of DM)	63	29.3	31.89	0	100.0	53	34.0	32.14	0	100.0
MEI[a] (MJ/day)	63	9.56	3.936	3.30	16.97	53	9.10	2.990	4.35	14.95
MEI (MJ/(day × kg $BW^{0.75}$))	63	0.876	0.2321	0.475	1.428	53	0.893	0.2250	0.548	1.309
ADG (g)	63	142	76.0	−86	294	53	132	73.4	−107	282
ADG (g/kg $BW^{0.75}$)	63	13.4	6.57	−7.7	26.6	53	13.6	6.84	−4.5	25.9

[a] ME intake.

Table 5
Summary of development and evaluation database sub-subsets for prediction of ME requirements for maintenance and gain of indigenous goats

Variable	Development					Evaluation				
	n	Mean	S.D.	Minimum	Maximum	*n*	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	87	17.9	7.91	7.6	43.0	70	14.9	5.55	6.4	30.6
DM intake (g/day)	87	526	184.6	206	931	70	483	185.4	188	851
CP (% of DM)	82	15.4	3.83	5.9	27.8	70	14.5	4.66	6.4	23.7
Forage (% of DM)	82	43.5	31.35	0	100.0	70	59.0	26.48	0	100.0
MEI[a] (MJ/day)	87	5.09	1.869	2.00	9.22	70	4.46	1.757	1.99	8.49
MEI (MJ/(day × kg $BW^{0.75}$))	87	0.591	0.1234	0.319	0.901	70	0.585	0.1189	0.329	0.794
ADG (g)	87	50.1	40.63	−84.0	177.2	70	44.2	28.57	−15.5	117.0
ADG (g/(day × kg $BW^{0.75}$))	87	6.00	4.858	−8.51	21.42	70	5.96	3.425	−2.35	16.96

[a] ME intake.

therefore considered more appropriate. As shown in Fig. 1, there were two observations in the development subset with negative ADG, three with an ADG of less than 5 g and four with an ADG of less than 15 g. Inclusion of these observations appreciably increased the range of observations in the subset; thus, influence of their inclusion was evaluated by regressions after removal. However, because MEI data also were low for these observations, removing them had a minimum effect, with no differences among intercepts or slopes. Intercepts were 482.6, 475.4 and 496.9 kJ/kg $BW^{0.75}$, slopes were 13.44, 14.66 and 13.03 kJ/g ADG

Table 6
Summary of the database for prediction of ME requirements for maintenance and gain of mature goats

Variable	*n*	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	69	25.1	10.70	12.3	55.8
DM intake (kg/day)	68	0.670	0.2452	0.291	1.297
CP (% of DM)	69	14.6	3.54	8.2	26.1
Forage (% of DM)	69	52.9	28.45	8.3	100.0
MEI[a] (MJ/day)	69	6.20	2.122	3.43	12.79
MEI (MJ/(day × kg $BW^{0.75}$))	69	0.575	0.1511	0.262	1.053
ADG (g)	69	39.7	31.76	−41.7	122.0
ADG (g/kg $BW^{0.75}$)	69	3.94	3.010	−2.04	10.18

[a] ME intake.

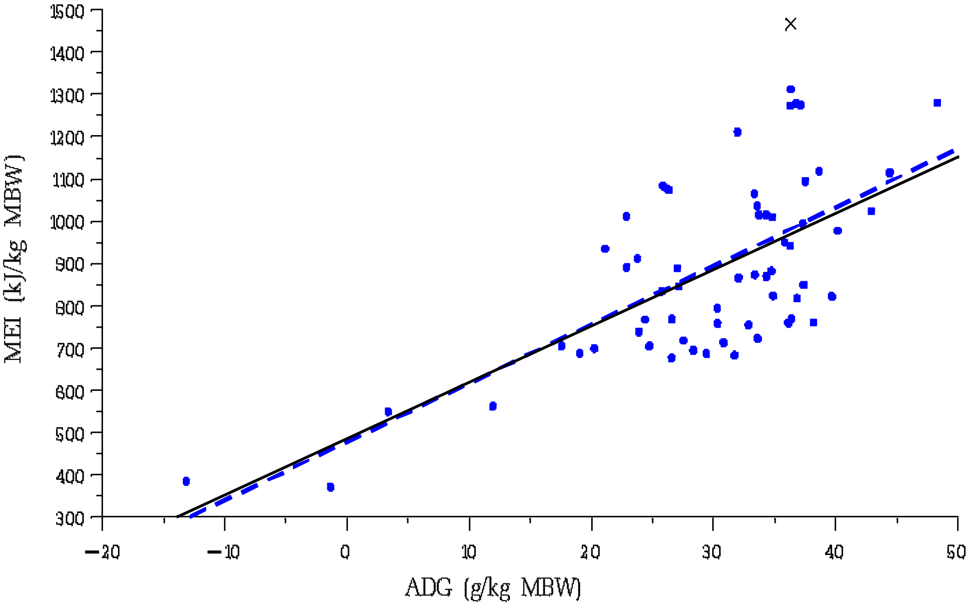

Fig. 1. The relationship between ME intake (MEI) and ADG of preweaning goats. Points are observed values, the dotted line (- - -) represents the regression line of all observations in the development subset and the solid line (—) is for the regression after removal of observations with high residuals (×: observations removed) and describes the equation: MEI = 484.6 (S.E. = 61.46) + (13.37 (S.E. = 1.95) × ADG) [$n = 61$; $R^2 = 0.44$]. MBW = kg $BW^{0.75}$.

and R^2 were 0.31, 0.27 and 0.22 after removal of observations with an ADG of less than 0, 5 and 15 g, respectively.

To evaluate Eq. (2), the evaluation subset was used to predict MEI values, and observed MEI values were regressed against predicted MEI values (MEI_{pred}). The intercept and slope of this regression equation ($MEI = 20.6$ (S.E. = 211.7) + 0.97 (S.E. = 0.24) × MEI_{pred}) did not differ from 0 ($P = 0.92$) and 1 ($P = 0.89$), respectively. Hence, Eq. (2) gave unbiased estimates of ME_m and ME_g for preweaning goats, which were 484.6 kJ/$BW^{0.75}$ and 13.37 kJ/g ADG, respectively.

3.2. Growing database

3.2.1. Meat subset

The equation for the regression of MEI against ADG was:

$$\begin{aligned}\mathrm{MEI} &= 464.9(\mathrm{S.E.} = 24.7)\\ &\quad + (25.28(\mathrm{S.E.} = 1.93) \times \mathrm{ADG}),\\ &\qquad n = 60,\ R^2 = 0.75 \end{aligned} \tag{3}$$

There were three observations with residuals greater than 2 rS.D.; all were for treatment mean observations with Boer crossbreds, and there were no other distinctive characteristics noted. After removing these three observations, the equation was:

$$\begin{aligned}\mathrm{MEI} &= 457.0(\mathrm{S.E.} = 22.3)\\ &\quad + (25.23(\mathrm{S.E.} = 1.74) \times \mathrm{ADG}),\\ &\qquad n = 57,\ R^2 = 0.79 \end{aligned} \tag{4}$$

Regression lines of Eqs. (3) and (4) are presented in Fig. 2. Eq. (4) estimates of ME_m and ME_g of growing meat goats were 457.0 kJ/$BW^{0.75}$ and 25.23 kJ/g ADG, respectively.

3.2.2. Dairy subset

The equation for the regression of MEI against ADG was:

$$\begin{aligned}\mathrm{MEI} &= 588.7(\mathrm{S.E.} = 53.7)\\ &\quad + (21.41(\mathrm{S.E.} = 3.60) \times \mathrm{ADG}),\\ &\qquad n = 63,\ R^2 = 0.37 \end{aligned} \tag{5}$$

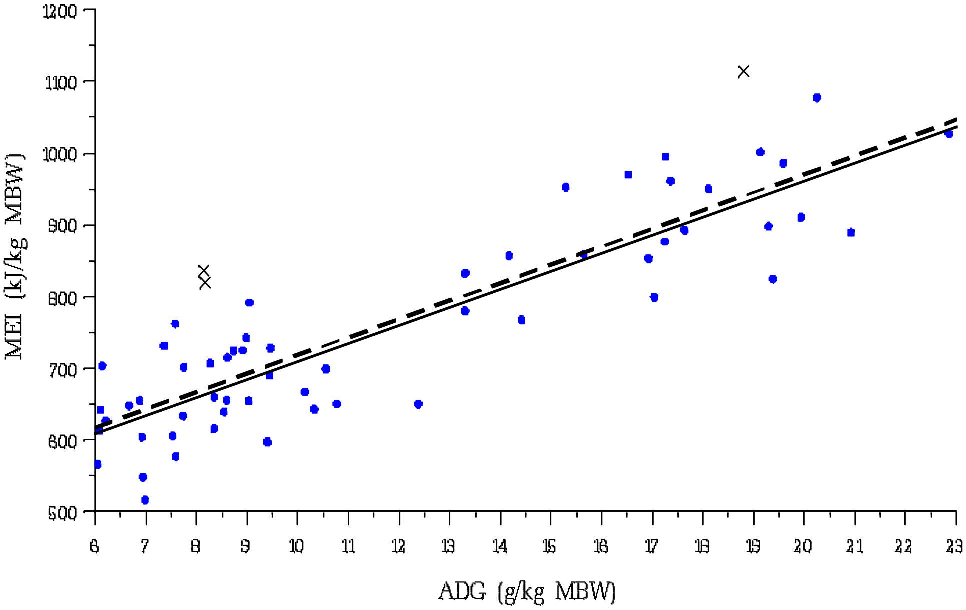

Fig. 2. The relationship between ME intake (MEI) and ADG of growing meat goats (≥50% Boer). Points are observed values, the dotted line (- - -) represents the regression line of all observations in the development subset and the solid line (—) is for the regression after removal of observations with high residuals (×: observations removed) and describes the equation: MEI = 457.0 (S.E. = 22.30) + (25.23 (S.E. = 1.74) × ADG) [$n = 57$; $R^2 = 0.79$]. MBW = kg $BW^{0.75}$.

Seven observations (11% of the development sub-subset) had residuals greater than 1.5 rS.D., which were removed; further removal of observations did not increase the R^2 or decrease RMSE. Observations removed were from high-producing dairy breeds (i.e., Saanen and Damascus) with relatively high BW gain, low MEI and low dietary forage concentration (14% forage for six of the observations). No other unique characteristics were detected. The following modified equation was obtained:

$$\begin{aligned}\mathrm{MEI} &= 573.7(\mathrm{S.E.} = 46.2)\\ &\quad + (23.56(\mathrm{S.E.} = 3.10) \times \mathrm{ADG}),\\ &\qquad n = 56,\ R^2 = 0.52 \qquad (6)\end{aligned}$$

Regression lines of Eqs. (5) and (6) are presented in Fig. 3. From Eq. (6), estimates of $\mathrm{ME_m}$ and $\mathrm{ME_g}$ of growing dairy goats were 573.7 kJ/$BW^{0.75}$ and 23.56 kJ/g ADG, respectively.

MEI data for the evaluation sub-subset were predicted from Eq. (6). The regression equation of observed MEI against $\mathrm{MEI_{pred}}$ was: MEI = 169.5 (S.E. = 144.6) + 0.81 (S.E. = 0.16) × $\mathrm{MEI_{pred}}$. The intercept and slope of the regression did not differ from 0 ($P = 0.25$) and 1 ($P = 0.23$), respectively. Thus, Eq. (6) provided unbiased estimates of $\mathrm{ME_m}$ and $\mathrm{ME_g}$ of growing dairy goats.

3.2.3. Indigenous subset

The equation for the regression of MEI against ADG was:

$$\begin{aligned}\mathrm{MEI} &= 497.8(\mathrm{S.E.} = 16.7)\\ &\quad + (15.60(\mathrm{S.E.} = 2.17) \times \mathrm{ADG}),\\ &\qquad n = 87,\ R^2 = 0.38 \qquad (7)\end{aligned}$$

Eleven observations (13% of the development sub-subset) had residuals greater than 1.5 rS.D., and these observations were removed. Although some of the removed observations were with diets fairly low in percentage of dietary forage, some were not, and other observations with low dietary forage fell on or close to the regression line. The regression equation

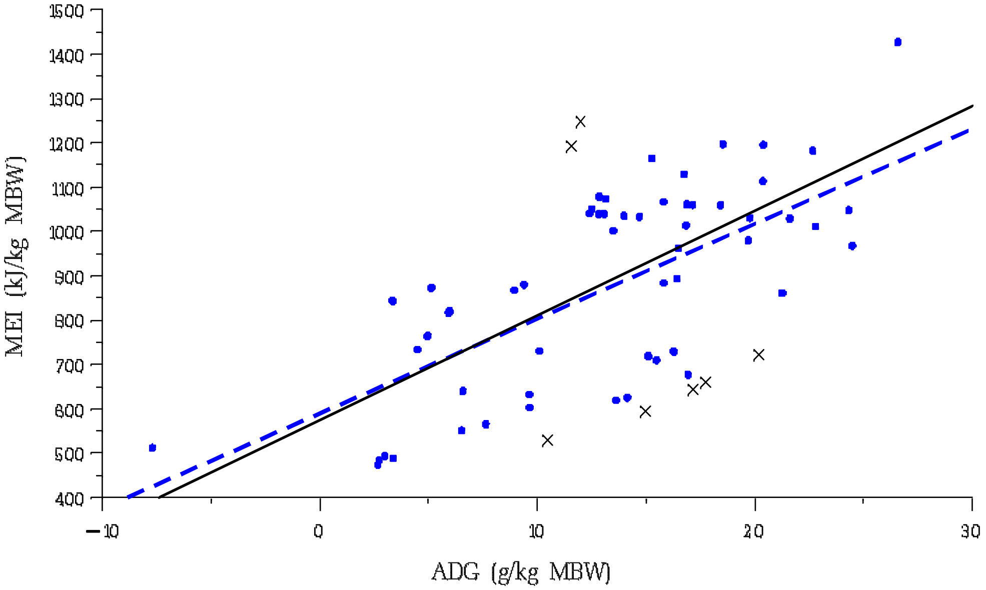

Fig. 3. The relationship between ME intake (MEI) and ADG of growing dairy goats. Points are observed values, the dotted line (- - -) represents the regression line of all observations in the development sub-subset and the solid line (—) is for the regression after removing observations with high residuals (x: observations removed) and describes the equation: MEI = 573.7 (S.E. = 46.20) + (23.56 (S.E. = 3.10) × ADG) [$n = 56$; $R^2 = 0.52$]. MBW = kg $BW^{0.75}$.

for the remaining observations was:

$$\begin{aligned}\text{MEI} = {} & 500.0(\text{S.E.} = 11.9)\\ & + (18.59(\text{S.E.} = 1.64) \times \text{ADG}),\\ & n = 76,\ R^2 = 0.63 \quad (8)\end{aligned}$$

Regression lines of Eqs. (7) and (8) are presented in Fig. 4. Estimates of ME_m and ME_g from Eq. (8) for growing indigenous goats were 500.0 kJ/$BW^{0.75}$ and 18.59 kJ/g ADG, respectively.

The regression of observed against MEI_{pred} with the evaluation data sub-subset resulted in the equation: MEI = −26.4 (S.E. = 117.4) + 1.00 (S.E. = 0.19) × MEI_{pred}, with an intercept and slope not different from 0 ($P = 0.82$) and 1 ($P = 0.90$), respectively. Therefore, Eq. (8) provided unbiased estimates of ME_m and ME_g of growing indigenous goats.

3.2.4. Growing database – final equations

Because of the removal of some observations from the development subset for meat goats and sub-subsets for dairy and indigenous goats, final equations (Eqs. (4), (6) and (8)) were tested for differences by analysis of covariance as performed previously. There was a difference ($P < 0.03$) in intercepts but not in slopes ($P = 0.16$). To investigate the difference in intercepts among meat, dairy and indigenous goats, two dummy variables ($D_1 = 1$ for meat and 0 otherwise; $D_2 = 1$ for dairy and 0 otherwise; D_1 and $D_2 = 0$ for indigenous) were used in regression analysis. The coefficient for D_1 did not differ from 0 ($P = 0.58$), indicating similar intercepts for meat and indigenous goats. Hence, D_1 was dropped from the model. In the reduced regression model, one dummy variable was used ($D = 1$ if dairy and 0 otherwise). The resulting common slope equation for the regression was:

$$\begin{aligned}\text{MEI} = {} & 480.0(\text{S.E.} = 13.5)\\ & + (103.2(\text{S.E.} = 17.38) \times D)\\ & + (22.85\,(\text{SE} = 1.23) \times \text{ADG}),\\ & n = 189,\ R^2 = 0.74 \quad (9)\end{aligned}$$

Regression lines of Eq. (9) are presented in Fig. 5. From Eq. (9), ME_m for growing dairy and non-dairy goats was 583.2 kJ/$BW^{0.75}$ and 480.0 kJ/$BW^{0.75}$, respectively, and ME_g for all growing goats was 22.85 kJ/g ADG. However, because the difference

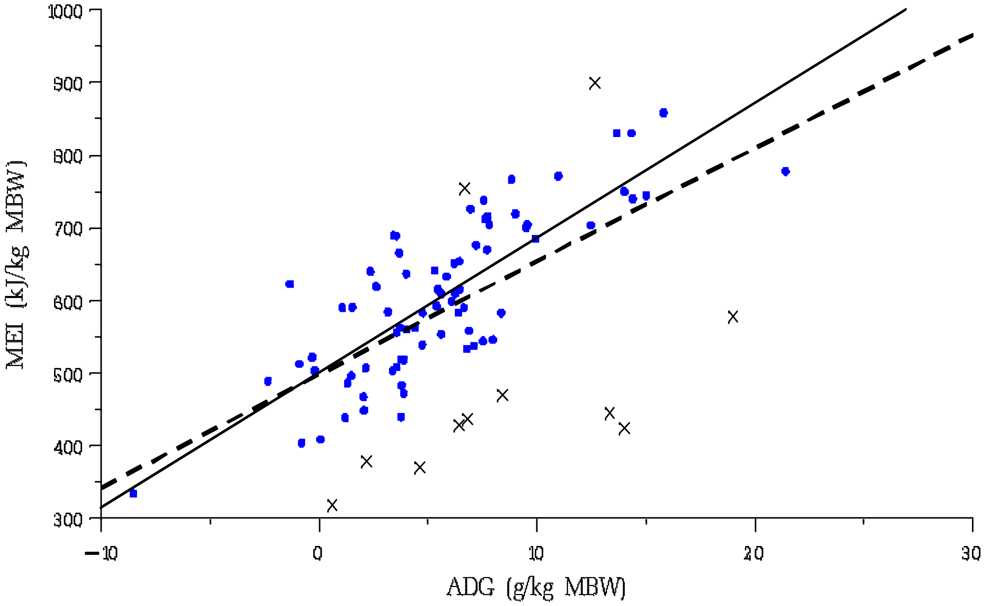

Fig. 4. The relationship between MEI and ADG of growing indigenous goats. Points are observed values, the dotted line (- - -) represents the regression line of all observations in the development sub-subset and the solid line (—) is for the regression after removing observations with high residuals (×: observations removed) and describes the equation: MEI = 500.0 (S.E. = 11.94) + (18.59 (S.E. = 1.64) × ADG) [$n = 76$; $R^2 = 0.63$]. MBW = kg $BW^{0.75}$.

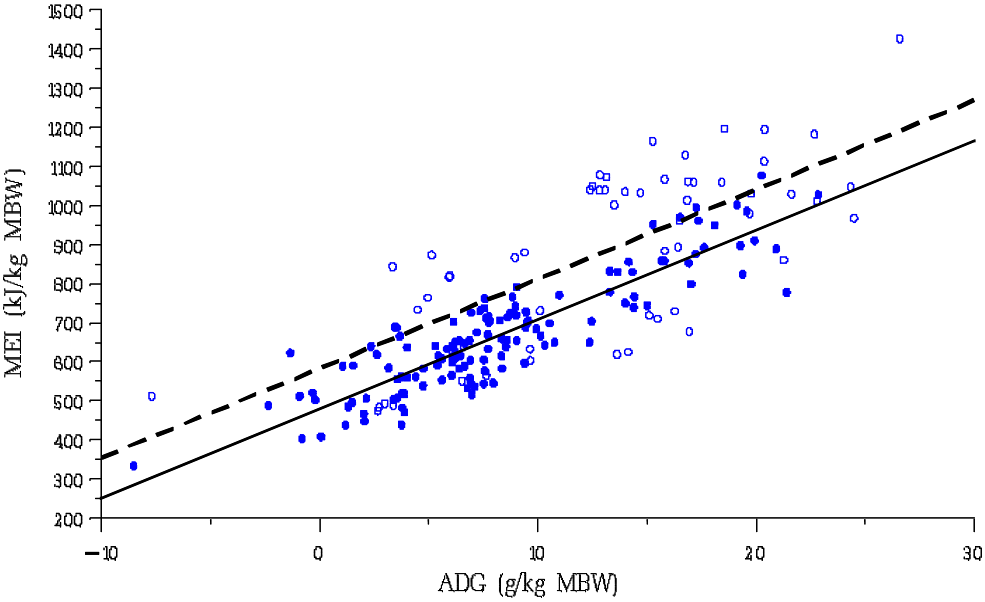

Fig. 5. The relationship between MEI and ADG of growing goats. Circles (○) are observations for dairy goats and dots (●) are observations for meat (≥Boer) and indigenous goats. The dotted line (- - -) describes the relationship for dairy goats and the solid line (—) is for meat and indigenous goats. The common slope equation is: MEI = 480.0 (S.E. = 13.52) + (103.2 (S.E. = 17.38) × D) + (22.85 (S.E. = 1.23) × ADG) [$n = 189$; $R^2 = 0.74$]. $D = 1$ for dairy goats and 0 otherwise. MBW = kg $BW^{0.75}$.

among biotype slopes approached significance ($P = 0.16$), another equation with two dummy variables ($I_1 = 1$ for dairy and 0 for others; $I_2 = 1$ for indigenous and 0 for others) was developed to investigate this trend. The dummy variable I_1 reflected a common intercept for growing meat and indigenous goats and the interaction of I_2 and ADG a common slope for growing dairy and meat goats. The final multiple regression equation was:

$$\begin{aligned}\text{MEI} = {} & 488.5(\text{S.E.} = 14.4) \\ & + (91.5(\text{S.E.} = 18.69) \times I_1) \\ & + (23.09(\text{S.E.} = 1.24) \times \text{ADG}) \\ & - (3.28(\text{S.E.} = 1.98) \times \text{ADG} \times I_2), \\ & n = 189,\ \text{R}^2 = 0.74 \quad (10)\end{aligned}$$

Eq. (10) yielded estimates for ME_m of 488.5, 579.9 and 488.5 kJ/kg $\text{BW}^{0.75}$ and ME_g of 23.09, 23.09 and 19.81 kJ/g ADG for meat, dairy and indigenous goats, respectively. Regression lines for Eq. (10) are shown in Fig. 6.

3.3. Mature database

The equation for the regression of MEI against ADG was:

$$\begin{aligned}\text{MEI} = {} & 462.2(\text{S.E.} = 24.95) \\ & + (28.52(\text{S.E.} = 5.05) \times \text{ADG}), \\ & n = 69,\ R^2 = 0.32 \quad (11)\end{aligned}$$

Removal of two observations with high residuals of greater than 2 rS.D. decreased the R^2; thus, these observations were not removed from the dataset. Eq. (11) estimates of ME_m and ME_g were 462.2 kJ/$\text{BW}^{0.75}$ and 28.52 kJ/g ADG, with the regression line shown in Fig. 7. As noted with the preweaning development subset, there were five observations with negative ADG; however, intercepts and slopes with and without these observations were similar; removal of these observations resulted in a numerical decrease in ME_m (462.2–449.8 kJ/kg $\text{BW}^{0.75}$), increase in ME_g (28.52–30.67 kJ/g ADG) and decrease in R^2 (0.32–0.29).

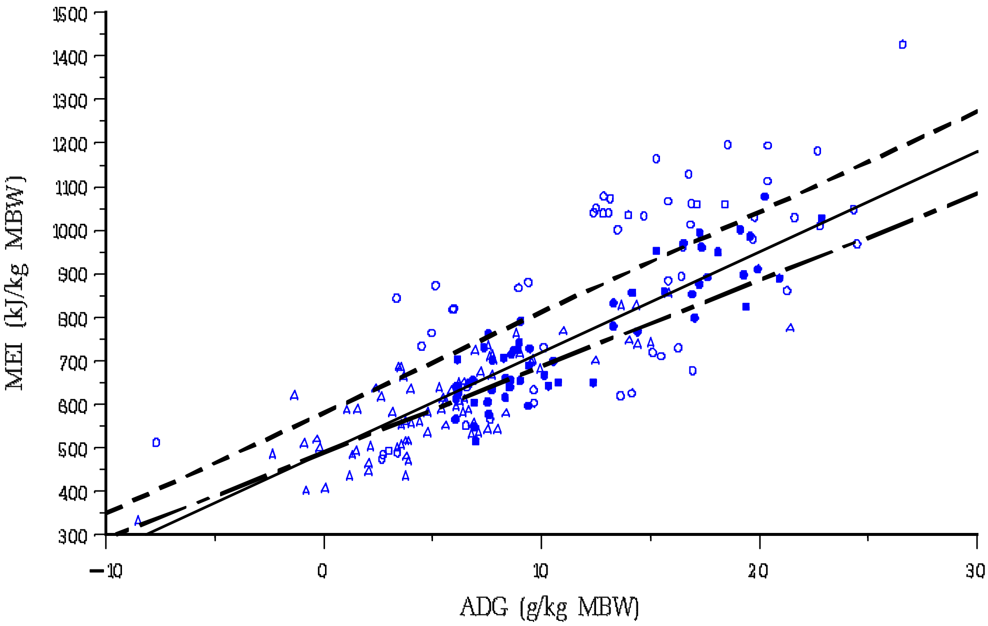

Fig. 6. The relationship between ME intake (MEI) and ADG of growing goats. Circles (○), dots (●) and triangles (▲) are observations for growing dairy, meat (≥Boer) and indigenous goats, respectively. The dotted line (- - -) is for dairy goats, the solid line (—) is for meat goats and the mixed line (–·–) is for indigenous goats. The multiple regression equation is: MEI = 488.5 (S.E. = 14.41) + (91.5 (S.E. = 18.69) × D_1) + (23.09 (S.E. = 1.24) × ADG) − (3.28 (S.E. = 1.98) × D_2 × ADG) [$n = 189$; $R^2 = 0.74$]. $D_1 = 0$ and $D_2 = 0$ for meat goats; $D_1 = 1$ and $D_2 = 0$ for dairy goats; and $D_1 = 0$ and $D_2 = 1$ for indigenous goats. MBW = kg $\text{BW}^{0.75}$.

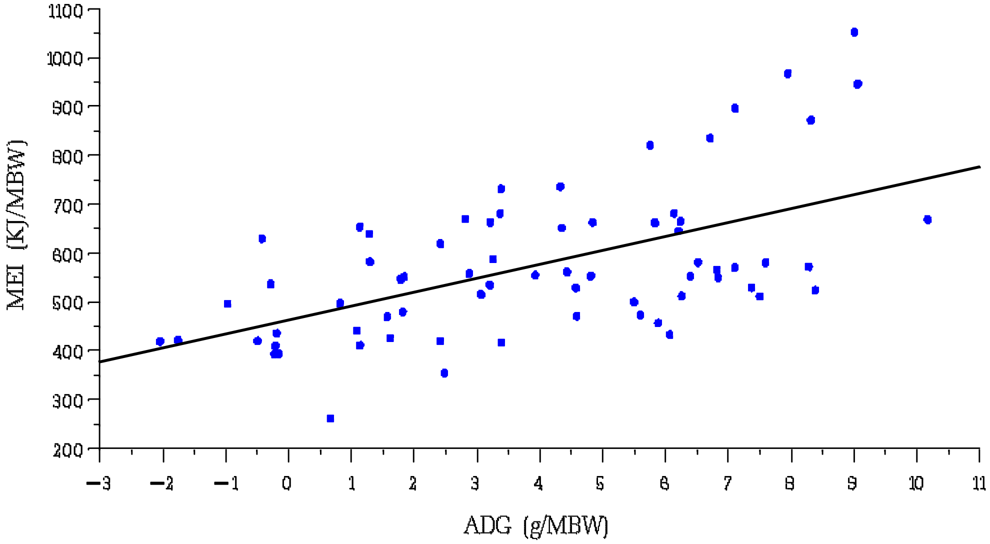

Fig. 7. The relationship between ME intake (MEI) and ADG of mature goats. Points are observed values and the line describes the equation: MEI = 462.2 (S.E. = 24.95) + (28.52 (S.E. = 5.05) × ADG) [$n = 69$; $R^2 = 0.32$]. MBW = kg $BW^{0.75}$.

4. Discussion

4.1. Procedural considerations

4.1.1. Independent variable

Selection of independent and dependent variables for regression analyses can affect the estimates of intercepts and slopes of regressions (Zemmelink et al., 1991; Johnson et al., 1998). The magnitude of this effect depends on characteristics of the database. With a database in which variability is relatively small and, more importantly, similar between variables, there is little or negligible influence.

One factor that contributes to choice of independent variable is the intended use of the regression equations. The primary purpose of regressions in the present study was to determine ME_m and ME_g requirements of goats rather than to predict BW change at a particular MEI, suggesting the use of ADG as the independent variable. Moreover, this approach facilitates estimation of the S.E. of ME_m (intercept) and ME_g (regression coefficient). A second important factor is variation in the two variables. 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 variable (Daniel and Wood, 1980; Johnson et al., 1998). In this study, ADG was directly determined for all observations. Of the 108 publications, there were 93 in which dietary ME concentration was either reported or calculated from determined digestibility or metabolizability coefficients. In some reports, ME concentration was based on dietary concentrations of ingredients and their ME concentration from literature sources. For other studies, fecal output or excretion of feces and urine were determined. Total fecal collections were performed in some studies, whereas in others markers were used for indirect estimation of fecal output. Fecal output, along with assumptions for methane or urine and methane energy losses allowed estimation of dietary ME concentration. For the 15 publications that did not report ME concentration in the diet, estimates were derived from ingredient composition and feedstuff ME concentrations listed in NRC (1981, 1984). Based on how ADG and MEI were estimated, greater variation in MEI than ADG was assumed, suggesting use of ADG as the independent variable.

4.1.2. Database splitting and equation evaluation

In order to assess whether models developed from literature databases are useful, it is desirable to evaluate the models with an independent data set. Hence, in the present study databases or subsets were divided when possible, based on reference or publication as described by Moore et al. (1999). For preweaning goats, because of a relatively small number of publications, similar subsets could only be achieved by randomly splitting treatment mean observations (Montgomery and Peck, 1982).

One disadvantage of database splitting is decreased precision in estimating intercepts and slopes. The S.E. are greater than when all data are used in equation development. Nonetheless, intercepts not different from 0 and slopes not different from 1 for regressions of observed values of evaluation data sets against values predicted with equations from development data sets suggest acceptable precision and accuracy in the present study.

4.2. ME_m

4.2.1. Preweaning

Similar ME_m of preweaning and growing meat and indigenous goats could be partially a result of differences in experimental conditions. Preweaning goats consuming primarily liquid feeds were in most cases confined to small pens or cages, suggesting minimal energy use for activity. Nonetheless, our preweaning goat ME_m estimate (485 ± 61.5 kJ/kg $BW^{0.75}$) was not greatly different from comparative slaughter estimates reported by Jagusch et al. (1983; 470 kJ/kg $BW^{0.75}$, 20 Saanen kids), Sanz Sampelayo et al. (1995; 465 kJ/kg $BW^{0.75}$, 32 Granadina kids) and Sanz Sampelayo et al. (1988; 427 kJ/kg $BW^{0.75}$, 18 Granadina kids).

4.2.2. Growing

ME_m estimates for growing goats (580 ± 16.5 kJ/kg $BW^{0.75}$ for dairy goats and 489 ± 14.4 kJ/kg $BW^{0.75}$ for non-dairy goats) were greater than that (431 kJ/kg $BW^{0.75}$) determined by Luo et al. (2004) with regression analysis involving treatment mean observations of heat production or recovered energy. This difference might be partially attributable to experimental conditions. In publications used by Luo et al. (2004), most goats were housed in relatively small areas, such as metabolism chambers or crates, whereas goats in the publications used in the present study were kept under more normal farm or production conditions; hence, greater energy use for activity would be expected (McDonald et al., 1977). However, reasons for differences between our estimates and others are unclear. For example, the NRC (1981) recommendation of 424 kJ/kg $BW^{0.75}$ was the average of 10 experimental values, ranging from 365 to 482 kJ/kg $BW^{0.75}$. Most of these values were derived from feeding trials and regression analyses, and one was calculated from cattle data. Zemmelink et al. (1991) reported a ME_m requirement of 384 kJ/kg $BW^{0.75}$ with 24 growing West African dwarf goats from a regression of BW gain against intake of digestible OM and Pralomkarn et al. (1995) determined a ME_m requirement of 376 kJ/kg $BW^{0.75}$ by regressing MEI against ADG with 24 growing Thai native goats that were housed indoors.

The 19% greater ME_m for growing dairy goats than for indigenous and meat goats agrees with greater maintenance energy requirements of Holstein than Hereford and other breeds of beef cattle (Garrett, 1971; Haaland et al., 1980, 1981; Fox and Black, 1984; Byers and Schelling, 1988). This difference may involve greater mass of metabolically active organs such as the liver, intestines, heart and kidneys (Webster, 1981) in goats that have been highly selected for milk production, which has been suggested as a reason for similar differences between dairy and beef cattle breeds (Ferrell et al., 1986; Dawson and Steen, 1998). Similarly, a ME_m estimate of 673 kJ/kg $BW^{0.75}$ (Kurar, 1983) for Alpine × Beetal goats was substantially greater than that for Beetal goats (523 kJ/kg $BW^{0.75}$, Kurar and Mudgal, 1981), presumably reflecting differences in maintenance requirements as influenced by the dairy biotype.

4.2.3. Mature

The ME_m of preweaning and growing goats in the present study were numerically higher than that of mature goats, which agrees with findings for other ruminant species (Graham et al., 1974; McDonald et al., 1977; ARC, 1980; AFRC, 1993; Geay, 1984). Metabolic rate relative to $BW^{0.75}$ is thought to decrease with advancing maturity (Freetly et al., 1995, 2002). The mature goat ME_m estimate (462 ± 25 kJ/kg $BW^{0.75}$) in the present study is similar to previous reports of NRC (1981: 424 kJ/kg $BW^{0.75}$) and AFRC (1998; 438 kJ/kg $BW^{0.75}$) for all goats, but greater than that of Onwuka and Akinsoyinu (1989; 408 kJ/kg $BW^{0.75}$) for mature goats.

Table 7
Summary of ME requirement for maintenance (ME_m) estimates for sheep and cattle

Source	Species	Breed	Forage (%)	No.	State	Sex	BW (kg)	Measured variable[a]	Method[b]	ME_m[c]
Steen et al., 1998	Sheep	Blackface × Texel	41	168	Growing	Mixed	31.5	HP	IC; RE ra MEI	462
	Sheep	Blackface × Texel	31	168	Growing	Mixed	31.5	HP	IC; RE ra MEI	468
	Sheep	Blackface × Texel	41	219	Growing	Mixed	31.5	RE	CS; RE ra MEI	495
	Sheep	Blackface × Texel	31	219	Growing	Mixed	31.5	RE	CS; RE ra MEI	492
Al Jassim et al., 1996	Sheep	Awassi	0	24	Growing	Mixed	24.4	BWC	BT; MEI ra BWC	466
Early et al., 2001	Sheep	Omani	20–60	40	Growing	Buck	27–34	BWC	FT; MEI ra BWC	494
	Sheep	Omani	20–60	40	Growing	Buck	27–34	TEG	FT; MEI ra TEG	612
	Sheep	Omani	20–60	40	Growing	Buck	27–34	EBW	FT; MEI ra EBW	589
	Sheep	Omani	20–60	40	Growing	Buck	27–34	TEG	FT; MEI ra TEG	706
Dawson and Steen, 1998	Sheep	Blackface cross	21–82	56	Growing	Wether	35–43	HP	IC; RE ra MEI	460
	Sheep	Blackface cross	21–82	56	Growing	Wether	35–43	HP	Equation; (FHP + A)/k_m	348
	Cattle	Charolais cross	25–80	75	Mature	Steer	505–566	HP	IC; RE ra MEI	614
	Cattle	Charolais cross	25–80	75	Mature	Steer	505–566	HP	Equation; (FHP + A)/k_m	459
Yan et al., 1998	Cattle	Holstein friesian	0–70	221	Lactating	Cow		HP	IC; RE ra MEI	670
Kirkland and Gordon, 1999	Cattle	Holstein friesian	18	8	Lactating	Cow	542–663	HP	IC; HP ra MEI	610
	Cattle	Holstein friesian	18	8	Lactating	Cow	542–663	HP	IC; RE ra MEI	610
	Cattle	Holstein friesian	18	8	Lactating	Cow	542–663	HP	IC; MEI ra BW and RE	610
Ferrell and Jenkins, 1998a	Cattle	Beef crossbred	13	70	Growing	Steer	330	RE	CS; RE ra MEI	495
	Cattle	Beef crossbred	13	70	Growing	Steer	330	RE	CS; HP ra MEI	529
Ferrell and Jenkins, 1998b	Cattle	Angus crossbred	13	8	Growing	Steer	346	RE	CS; HP ra MEI	395
	Cattle	Boran crossbred	13	15	Growing	Steer	277	RE	CS; HP ra MEI	413
	Cattle	Brahman crossbred	13	15	Growing	Steer	313	RE	CS; HP ra MEI	501
	Cattle	Hereford crossbred	13	8	Growing	Steer	286	RE	CS; HP ra MEI	428
	Cattle	Tuli crossbred	13	16	Growing	Steer	287	RE	CS; HP ra MEI	472
	Cattle	Angus crossbred	13	8	Growing	Steer	346	RE	CS; RE ra MEI	249
	Cattle	Boran crossbred	13	15	Growing	Steer	277	RE	CS; RE ra MEI	293
	Cattle	Brahman crossbred	13	15	Growing	Steer	313	RE	CS; RE ra MEI	488
	Cattle	Hereford crossbred	13	8	Growing	Steer	286	RE	CS; RE ra MEI	368
	Cattle	Tuli crossbred	13	16	Growing	Steer	287	RE	CS; RE ra MEI	418
Birkelo et al., 1991	Cattle	Hereford	40	8	Growing	Steer	410	HP, FHP	IC; FHP/k_m	496
Montano-Bermudez et al., 1990	Cattle	Angus crossbred		71	Lactating	Cow	493	BWC	FT; MEI ra BW and BWC	602
	Cattle	Angus crossbred		72	Pregnant	Cow	476	BWC	FT; MEI ra BW and BWC	498
	Cattle	Charolais cross		494	Growing	Steer and Heifers	370	BWC	FT; MEI ra BWC	588
	Cattle	Charolais cross		164	Growing	Steer	385	BWC	FT; MEI ra BWC	604
	Cattle	Charolais cross		330	Growing	Heifer	354	BWC	FT; MEI ra BWC	650
Reid et al., 1991	Cattle	Hereford	100	13	Mature	Cow	578	RE	CS; RE ra MEI	605
	Cattle	Red Poll	100	12	Mature	Cow	535	RE	CS; RE ra MEI	705
	Cattle	Hereford × Red Poll	100	7	Mature	Cow	567	RE	CS; RE ra MEI	621
	Cattle	Red Poll crossbred	100	11	Mature	Cow	569	RE	CS; RE ra MEI	624
	Cattle	Angus × Hereford	100	12	Mature	Cow	582	RE	CS; RE ra MEI	603
	Cattle	Angus × Charolais	100	12	Mature	Cow	604	RE	CS; RE ra MEI	637
	Cattle	Brahman × Hereford	100	12	Mature	Cow	632	RE	CS; RE ra MEI	580
	Cattle	Brahman × Angus	100	12	Mature	Cow	581	RE	CS; RE ra MEI	598
Solis et al., 1988	Cattle	Angus	70	4	Mature	Dry cow	504	RE	D_2O; RE ra MEI	383
	Cattle	Brahman	70	4	Mature	Dry cow	499	RE	D_2O; RE ra MEI	392
	Cattle	Hereford	70	4	Mature	Dry cow	490	RE	D_2O; RE ra MEI	399
	Cattle	Holstein	70	4	Mature	Dry cow	547	RE	D_2O; RE ra MEI	484
	Cattle	Jersey	70	4	Mature	Dry cow	395	RE	D_2O; RE ra MEI	587
	Cattle	Angus	70	4	Mature	Dry cow	504	BWC	FT; BWC ra MEI	418
	Cattle	Brahman	70	4	Mature	Dry cow	499	BWC	FT; BWC ra MEI	410
	Cattle	Hereford	70	4	Mature	Dry cow	490	BWC	FT; BWC ra MEI	452
	Cattle	Holstein	70	4	Mature	Dry cow	547	BWC	FT; BWC ra MEI	498
	Cattle	Jersey	70	4	Mature	Dry cow	504	BWC	FT; BWC ra MEI	636

[a] HP, heat production; FHP, fasting heat production; RE, recovered or retained energy; BWC, BW change; TEG, tissue energy gain; EBW, empty BW.

[b] IC, indirect calorimetry; CS, comparative slaughter; BT, balance trial; FT, feeding trial; D_2O, deuterium oxide dilution; MEI, ME intake; A, activity allowance; k_m, efficiency of ME use for maintenance; ra, regressed against.

[c] ME_m = kJ/kg $BW^{0.75}$.

4.3. ME_m of other ruminant species

As already noted, ME_m estimates of this study were generally greater than previous recommendations for goats (e.g., NRC, 1981; AFRC, 1998) as well as some values determined in specific studies. However, there have been relatively more determinations of ME_m with other ruminant species, examples of which are given in Table 7. Estimates of ME_m from the present study are within the range of these values for cattle and sheep, although the range is quite wide. These estimates support greater ME_m for dairy cattle than for beef cattle breeds, and also differences among other breeds or biotypes within a species.

4.4. ME_g

Considerably lower ME_g estimates for preweaning and growing goats compared with mature goats is in general agreement with findings for cattle (Rohr and Daenicke, 1984). This difference is probably the result of greater fat concentration in tissue gain by mature goats because of the higher energy concentration in fat than protein and higher concentration of water in lean than adipose tissue. Similarly, primarily lean tissue accretion by preweaning goats presumably contributed to relatively low ME_g. Likewise, Geay (1984) noted that cattle growing rapidly when young require less energy per unit of ADG than adults, and SCARM (1994) stated that the ME_g of preweaning lambs seems lower than that of growing and mature sheep.

Although literature estimates of ME_g for goats vary widely, values in the present study are within the range of previous estimates. For example, Akinsoyinu (1974) reported a ME_g of 22.85 kJ/g ADG for West African dwarf goats, and a value of 24.8 kJ/g ADG was reported for Australian cashmere goats by Ash and Norton (1987). Similarly, 25.9 kJ/g ADG was noted with Thai native goats (Pralomkarn et al., 1995) and 26.9 kJ/g ADG was estimated for Indian goats (Rajpoot, 1979). However, there also have been much greater estimates reported in the literature (NRC, 1981: 30.3 kJ/g ADG; Zemmelink et al., 1985: 44.4 kJ/g ADG; Zemmelink et al., 1991: 38.1 kJ/g ADG), which might be attributable to different methods or genotypes.

5. Conclusions

Treatment mean observations from published reports were used to construct databases to determine ME_m and ME_g requirements of goats by regressing MEI against ADG. ME_m was 485, 489, 580, 489 and 462 kJ/kg $BW^{0.75}$, and ME_g was 13.4, 23.1, 23.1, 19.8 and 28.5 kJ/g ADG for preweaning, growing meat, growing dairy, growing indigenous and mature goats, respectively. These estimates should be useful in diet formulation as well as prediction of performance of goats. However, goats in the reports used in this study were not subjected to appreciable stress, such as environmental or nutritional. Hence, application in some specific settings may require additional considerations.

Acknowledgements

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Appendix A. Publications in preweaning database

Andrighetto, I., Bailoni, L., Zancan, M., Dalvit, P., 1993. Effect of concentration of cold acidified milk replacers, breed and rearing season on the performance of goat kids. Small Rum. Res. 13, 223–229.

Economides, S., 1986. Comparative studies of sheep and goats: milk yield and composition and growth rate of lambs and kids. J. Agric. Sci. (Camb.) 106, 477–484.

Economides, S., Georghiades, E., Koumas, A., Hadjipanayiotou, M., 1989. The effect of cereal processing on the lactation performance of Chios sheep and Damascus goats and the pre-weaning growth of their offspring. Anim. Feed Sci. Technol. 26, 93–104.

Fehr, P.M., Sauvant, D., Delage, J., Dumont, B.L., Roy, G., 1976. Effect of feeding methods and age at slaughter on growth performance and carcass characteristics of entire young male goats. Livest. Prod. Sci. 3, 183–194.

Goetsch, A.L., Detweiler, G., Sahlu, T., Dawson, L.J., 2001. Effects of different management practices on preweaning and early postweaning growth of Alpine kids. Small Rum. Res. 41, 109–116.

Goetsch, A.L., Puchala, R., Lachica, M., Sahlu, T., Dawson, L., 2000. A note on the effect of restricted consumption of water and (or) dry matter in milk replacer on growth by male and female Alpine kids. J. Anim. Feed Sci. 9, 317–324.

Hadjipanayiotou, M., Koumas, A., Hadjigavriel, G., Antoniou, T., Photiou, A., Theodoridou, M., 1996. Feeding dairy ewes and goats and growing lambs and kids mixtures of protein supplements. Small Rum. Res. 21, 203–211.

Lindberg, J.E., 1989. Nitrogen metabolism and urinary excretion of purines in goat kids. Br. J. Nutr. 61, 309–321.

Luo, J., Sahlu, T., Cameron, M., Goetsch, A.L., 1999. Growth of Spanish, Boer × Angora and Boer × Spanish goat kids fed milk replacer. Small Rum. Res. 36, 189–194.

Pfeffer, E., Rodehutscord, M., 1998. Body chemical composition and utilization of dietary energy by male Saanen kids fed either milk to satiation or solid complete feeds with two proportions of straw. J. Agric. Sci. (Camb.) 131, 487–495.

Sanz Sampelayo, M.R., Munoz, F.J., Guerrero, J.E., Gil Extremera, F., Boza, J., 1988. Energy metabolism of the Granadina breed goat kid: use of goat milk and a milk replacer. J. Anim. Physiol. Anim. Nutr. 59, 1–9.

Sanz Sampelayo, M.R., Ruiz Mariscal, I., Gil Extremera, F., Boza, J., 1997. The effect of different concentrations of protein and fat in milk replacers on protein utilization in kid goats. Anim. Sci. 64, 485–492.

Tanabe, S., Kameoka, K., 1976. Effect of feeding a carbohydrate-free diet on the growth and metabolism of preruminant kids. Br. J. Nutr. 36, 47–59.

Voicu, I., Burlacu, Gh., Diana-Criste, R., Voicu, D., 1991. Energy and protein requirements in young female goats. In: Wenk, C., Boesinger, M. (Eds.), Energy Metabolism of Farm Animals. Institut fur Nutztierwisseschaften Gruppe Ernahrung, Zurich, Switzerland, pp. 150–153.

Yan, T., Cook, J.E., Gibb, M.J., Ivings, W.E., Treacher, T.T., 1993. The effects of quantity and duration of milk feeding on the intake of concentrates and growth of castrated male Saanen kids to slaughter. Anim. Prod. 56, 327–332.

Appendix B. Publications in growing database

Abate, A., 1989. Metabolizable energy requirements for maintenance of Kenyan goats. Small Rum. Res. 2, 299–306.

Abate, A., Pfeffer, E., 1986. Changes in nutrient intake and performance by goats fed coffee pulp-based diets followed by a commercial concentrate. Anim. Feed Sci. Technol. 14, 1–10.

Abdel-Rahman, K.M., El Kaschab, S., 1996. Nutritional performance of Damascus and Jamnapari crossbred goats. World Rev. Anim. Prod. 31, 55–58.

Adeloye, A.A., 1995. The value of cowpea husk to the goat. Biores. Technol. 52, 281–282.

Adeloye, A.A., Yousouf, M.B., 2001. Influence of nickel supplementation from nickel sulphate hexahydrate and nickel-sodium monofluorophosphate on the performance of the West African dwarf kids. Small Rum. Res. 39, 195–198.

Anandan, S., Sastry, V.R.B., Musalia, L.M., Agrawal, D.K., 1996. Growth rate and nutrient efficiency of growing goats fed urea ammoniated neem (*Azadirachta indica*) seed kernel meal as protein supplement. Small Rum. Res. 22, 205–212.

Ash, A.J., Norton, B.W., 1987. Studies with the Australian cashmere goat. Part I. Growth and digestion in male and female goats given pelleted diets varying in protein content and energy level. Aust. J. Agric. Res. 38, 957–969.

Ash, A.J., Petaia, L., Ako, H., 1992. Nutritional value of *Sesbania grandiflora* leaves for monogastrics and ruminants. Trop. Agric. 69, 223–228.

Astuti, D.A., Sastradipradja, D., Sutardi, T., Haryanto, B., 1997. Energy and protein requirements of growing female Etawah crossbred goats determined from metabolic parameters. In: McCracken, K.J., Unsworth, E.F., Wylie, A.R.G. (Eds.), Energy Metabolism of Farm Animals. CAB International, Belfast, UK, pp. 59–62.

Bamikole, M.A., Ezenwa, I., Akinsoyinu, A.O., Arigbede, M.O., Babayemi, O.J., 2001. Performance of West African dwarf goats fed Guinea grass-Verano stylo mixture, N-fertilized and unfertilized Guinea grass. Small Rum. Res. 39, 145–152.

Beede, D.K., Schelling, G.T., Mitchell Jr., G.E., Tucker, R.E., 1985. Utilization by growing goats of diets that contain monensin and low or excess crude protein: comparative slaughter experiment. J. Anim. Sci. 61, 1230–1242.

Beede, D.K., Schelling, G.T., Mitchell Jr., G.E., Tucker, R.E., Gill, W.W., Koenig, S.E., Lindsey, T.O., 1986. Nitrogen utilization and digestibility by growing steers and goats of diets that contain monensin and low crude protein. J. Anim. Sci. 62, 857–863.

Cameron, M., Luo, J., Sahlu, T., Hart, S.P., Coleman, S.W., Goetsch, A.L., 2001. Growth and slaughter traits of Boer × Spanish, Boer × Angora, and Spanish goats consuming a concentrate-based diet. J. Anim. Sci. 79, 1423–1430.

Cameron, M.R., Hart, S.P., Sahlu, T., Gilchrist, C., Coleman, S.W., Goetsch, A.L., 2001. Effects of gender and age on performance and harvest traits of Boer × Spanish goats. J. Appl. Anim. Res. 20, 141–155.

Cochran, R.C., Del Carpio, A., Parker, C.F., Hallford, D.M., Van Keuren, R.W., 1984. Growth response of Peruvian Criollo goats consuming varying levels of *Acacia macracantha, Leucaena leucocephala* and corn stalks. Nutr. Rep. Int. 29, 495–503.

Economides, S., 1986. Comparative studies of sheep and goats: milk yield and composition and growth rate of lambs and kids. J. Agric. Sci. (Camb.) 106, 477–484.

Economides, S., Koumas, A., Georghiades, E., Hadjipanayiotou, M., 1990. The effect of barley-sorghum grain processing and form of concentrate mixture on the performance of lambs, kids and calves. Anim. Feed Sci. Technol. 31, 105–116.

El-Hag, M.G., El Shargi, K.M., 1998. Chemical composition and feeding value of chopped date fronds (CDF) as affected by urea and date syrup extract treatment. Asian-Australasian J. Anim. Sci. 11, 685–691.

El Muola, I.H.A., Babiker, S.A., El Khidir, O.A., Ibrahim, S.E., 1999. Meat production from female goat kids compared with males. J. Agric. Sci. (Camb.) 133, 223–226.

Fehr, P.M., Sauvant, D., Delage, J., Dumont, B.L., Roy, G., 1976. Effect of feeding methods and age at slaughter on growth performances and carcass characteristics of entire young male goats. Livest. Prod. Sci. 3, 183–194.

Galgal, K.K., Norton, B.W., 1991. The value of Copra meal expeller pellets as concentrate feed for weaner goats. In: Saithanoo, S., Norton, B.W. (Eds.), Goat Production in the Asian Humid Tropics. The Australian International Development Assistance Bureau, Hat Yai, Thailand, pp. 144–153.

Gelaye, S., Amoah, E.A., 1991. Nutritive value of florigraze rhizoma peanut as an alternative leguminous forage for goats. Small Rum. Res. 6, 131–139.

Gelaye, S., Amoah, E.A., Guthrie, P., 1990. Performance of yearling goats fed alfalfa and florigraze rhizoma peanut hay. Small Rum. Res. 3, 353–361.

Gipson, T., 1999. Meat buck performance test. In: Proc. of the 14th Annual Goat Field Day. Agricultural Research and Extension Program, Langston University, Langston, OK, pp. 123–124.

Gipson, T., 2000. Meat buck performance test. In: Proc. of the 15th Annual Goat Field Day. Agricultural Research and Extension Program, Langston University, Langston, OK, pp. 41–44.

Gipson, T., 2001. Meat buck performance test. In: Proc. of the 16th Annual Goat Field Day. Agricultural Research and Extension Program, Langston University, Langston, OK, pp. 102–106.

Goetsch, A.L., Detweiler, G., Sahlu, T., Dawson, L.J., 2001. Effects of different management practices on preweaning and early postweaning growth of Alpine kids. Small Rum. Res. 41, 109–116.

Hadjipanayiotou, M., Koumas, A., Hadjigavriel, G., Antoniou, T., Photiou, A., Theodoridou, M., 1996. Feeding dairy ewes and goats and growing lambs and kids mixtures of protein supplements. Small Rum. Res. 21, 203–211.

Havrevoll, O., Rajbhandari, S.P., Eik, L.O., Nedkvitne, J.J., 1995. Effects of different energy levels during indoor rearing on performance of Norwegian dairy goats. Small Rum. Res. 15, 231–237.

Ivey, D.S., Owens, F.N., Sahlu, T., Teh, T.H., Claypool, P.L., Goetsch, A.L., 2000. Growth and cashmere production by Spanish goats consuming ad libitum diets differing in protein and energy levels. Small Rum. Res. 35, 133–139.

Johnson, T.J., Gherardi, S.G., Dhaliwal, S., 1994. Diet quality effects the cashmere production and liveweight of Western Australian cashmere goats. Aust. J. Exp. Agric. 34, 1107–1112.

Kibria, S.S., Nahar, T.N., Mia, M.M., 1994. Tree leaves as alternative feed resource for Black Bengal goats under stall-fed conditions. Small Rum. Res. 13, 217–222.

Kibria, S.S., Roxas, D.B., Ranjhan, S.K., 1996. Water hyacinth (*Eichhornia crassipes* Mart, Solm) silage as feed for goat. In: Holst, P.J. (Ed.), VI Int. Conf. Goats, International Academic Publishers, Beijing, China, pp. 619–623.

Louca, A., Economides, S., Hancock, J., 1977. Effects of castration on growth rate, feed conversion efficiency and carcass quality in Damascus goats. Anim. Prod. 24, 387–391.

Louca, A., Hancock, J., 1977. Genotype by environment interactions for postweaning growth in the Damascus breed of goat. J. Anim. Sci. 44, 927–931.

Louca, A., Papas, A., 1973. The effect of different proportions of carob pod meal in the diet on the performance of calves and goats. Anim. Prod. 17, 139–146.

Lu, C.D., Potchoiba, M.J., 1988. Milk feeding and weaning of goat kids--a review. Small Rum. Res. 1, 105–112.

Lu, C.D., Potchoiba, M.J., 1990. Feed intake and weight gain of growing goats fed diets of various energy and protein levels. J. Anim. Sci. 68, 1751–1759.

Luginbuhl, J.M., Poore, M.H., Conrad, A.P., 2000a. Effect of level of whole cottonseed on intake, digestibility, and performance of growing male goats fed hay-based diets. J. Anim. Sci. 78, 1677–1683.

Luginbuhl, J.M., Poore, M.H., Spears, J.W., Brown, T.T., 2000b. Effect of dietary copper level on performance and copper status of growing meat goats. Sheep and Goat Res. J. 16, 65–71.

Luo, J., Sahlu, T., Goetsch, A.L., 2000. Growth and carcass traits of Boer × Alpine goats slaughtered at the ages of 31 and 50 weeks. J. Anim. Feed Sci. 9, 309–324.

Marisco, G., Laudadio, V., Pinto, F., Vicenti, A., Vonghia, G., Ciruzzi, B., 1996. The utilization of olive leaves and twigs in the production of 100 days kids. In: Holst, P.J. (Ed.), VI Int. Conf. on Goats, International Academic Publishers, Beijing, China, pp. 635–642.

Mishra, R.M., Panda, N.C., Sahu, B.K., Rao, A.T., 1987. High potassium as incriminating factor in water hyacinth. Indian J. Anim. Sci. 57, 991–999.

Mtenga, L.A., Kitaly, A.J., 1990. Growth performance and carcass characteristics of Tanzanian goats fed *Chloris gayana* hay with different levels of protein supplement. Small Rum. Res. 3, 1–8.

Negesse, T., Rodehutscord, M., Pfeffer, E., 2001. The effect of dietary crude protein level on intake, growth, protein retention and utilization of growing male Saanen kids. Small Rum. Res. 39, 243–251.

Njwe, R.M., 1990. Energy requirement of Cameroon dwarf goat. World Rev. Anim. Prod. 25, 61–65.

Njwe, R.M., 1992. Protein requirements of Cameroonian Dwarf goats. World Rev. Anim. Prod. 27, 23–29.

Osuji, P.O., 1987. Intensive feeding systems for goats in Latin America and the Carribean. In: Santana, O.P., da Silva, A.G., Foote, W.C. (Eds.), IV Int. Conf. on Goats, Departamento de Difusao de Tecnologia, Brasilia, Brazil, pp. 1077–1108.

Pfeffer, E., Rodehutscord, M., 1998. Body chemical composition and utilization of dietary energy by male Saanen kids fed either milk to satiation or solid complete feeds with two proportions of straw. J. Agric. Sci. (Camb.) 131, 487–495.

Prieto, I., Goetsch, A.L., Banskalieva, V., Cameron, M., Puchala, R., Sahlu, T., Dawson, L.J., Coleman, S.W., 2000. Effects of dietary protein concentration on postweaning growth of Boer crossbred and Spanish goat wethers. J. Anim. Sci. 78, 2275–2281.

Qi, K., Lu, C.D., Owens, F.N., 1993. Sulfate supplementation of growing goats: effects on performance, acid-base balance, and nutrient digestibilities. J. Anim. Sci. 70, 1579–1587.

Rai, S.N., Harika, A.S., 1992. Effect of long-term feeding of Leucaena leaf-meal (LLM) as a protein source on feed utilization and growth in crossbred kids. In: Lokeshwar, R.R. (Ed.), Recent Advances in Goat Production. V Int. Conf. on Goats, Nutan Printers, New Delhi, India, pp. 757–760.

Rengsirikul, B., Sae Nai, P., 1991. The use of palm oil meal with urea-treated rice straw in post-weaning goat rations. In: Saithanoo, S., Norton, B.W. (Eds.), Goat Production in the Asian Humid Tropics. The Australian International Development Assistance Bureau, Hat Yai, Thailand, pp. 154–163.

Richards, D.E., Brown, W.F., Ruegsegger, G., Bates, D.B., 1994. Replacement value of tree legumes for concentrates in forage-based diets. Part I. Replacement value of *Gliricidia sepium* for growing goats. Anim. Feed Sci. Technol. 46, 37–51.

Rodriguez, W.E., Murillo, B., Velez, M., 1992a. *Gliricidia sepium* leaves as a forage. Part I. Intake and digestibility. In: Lokeshwar, R.R. (Ed.), Recent Advances in Goat Production. V Int. Conf. on Goats, Nutan Printers, New Delhi, India, pp. 761–764.

Rodriguez, W.E., Velez, M., Esnaola, M.A., 1992b. *Gliricidia sepium* leaves as a forage. Part 2. Kids and lamb fattening. In: Lokeshwar, R.R. (Ed.), Recent Advances in Goat Production. V Int. Conf. on Goats, Nutan Printers, New Delhi, India, pp. 765–772.

Saikia, G., Baruah, K.K., Buragohain, S.C., Saikia, B.N., Pathak, N.N., 1995. Feed intake, utilization of nutrients and growth of Assamese × Beetal goats fed three levels of energy. Small Rum. Res. 15, 279–282.

Sooden-Karamath, S., Youssef, F.G., 1999. Effect of monensin, avoparcin and grass supplementation on utilization of urea-treated rice straw by sheep and goats. Small Rum. Res. 33, 201–211.

Sormunen-Cristian, R., Kangasmaki, T., 2000. Performance of Finnish Landrace goat kids and lambs raised under stall feeding conditions in Finland. Small Rumin. Res. 38, 109–114.

Soto-Navarro, S.A., Goetsch, A.L., Sahlu, T., Puchala, R., 2003. Effect of supplemental protein source on performance of Spanish × Boer wethers. Small Rum. Res. (in review).

Souri, M., Galbraith, H., Scaife, J.R., 1998. Comparison of the effect of genotype and protected methionine supplementation on growth, digestive characteristics and fibre yield in cashmere-yielding and Angora goats. Anim. Sci. 66, 217–223.

Vadiveloo, J., 1988. Performance of young indigenous and crossbred goats fed forages supplemented with palm oil mill effluent. Small Rum. Res. 1, 369–379.

Van Eys, J.E., Mathius, I.W., Pongsapan, P., Johnson, W.L., 1986. Foliage of the tree legumes gliricidia, leucaena, and sesbania as supplement to napier grass diets for growing goats. J. Agric. Sci. (Camb.) 107, 227–233.

Van Hao, N., Ledin, I., 2001. Performance of growing goats fed *Gliricidia maculata*. Small Rum. Res. 39, 113–119.

Verma, A.K., Sastry, V.R.B., Agrawal, D.K., 1995. Feeding of water washed neem (*Azadirachta indica*) seed kernel cake to growing goats. Small Rum. Res. 15, 105–111.

Virk, A.S., Khatta, V.K., Tewatia, B.S., Gupta, P.C., 1994. Effect of formaldehyde-treated faba beans (*Vicia faba* L.) on nutrient utilization and growth performance of goat kids. Small Rumin. Res. 14, 19–23.

Voicu, I., Burlacu, Gh., Diana-Criste, R., Voicu, D., 1991. Energy and protein requirements in young female goats. In: Wenk, C., Boesinger, M. (Eds.), Energy Metabolism of Farm Animals, Institut fur Nutztierwisseschaften Gruppe Ernahrung, Zurich, Switzerland, pp. 150–153.

Yami, A., Litherland, A.J., Davis, J.J., Sahlu, T., Puchala, R., Goetsch, A.L., 2000. Effects of dietary level of *Leucaena leucocephala* on performance of Angora and Spanish doelings. Small Rum. Res. 38, 17–27.

Yan, T., Cook, J.E., Gibb, M.J., Ivings, W.E., Treacher, T.T., 1993. The effects of quantity and duration of milk feeding on the intake of concentrates and growth of castrated male Saanen kids to slaughter. Anim. Prod. 56, 327–332.

Zemmelink, G., Tolkamp, B.J., Ogink, N.M.W., 1991. Energy requirements for maintenance and gain of West African Dwarf goats. Small Rum. Res. 5, 205–215.

Appendix C. Publications in mature database

Aganga, A.A., Umunna, N.N., Oyepide, E.O., Okoh, P.N., 1989. Effect of feed management on water intake of Yankasa sheep and Maradi goats. Trop. Vet. 7, 116–121.

Akinsoyinu, A.O., 1992. Grain replacement value of cassava peels for growing goats. Biores. Technol. 40, 143–147.

Akinsoyinu, A.O., Ologhobo, A.D., 1989. Studies on comparative utilization of activated sewage sludge, poultry droppings and groundnut cake in cassava-based rations by goats. Biol. Wastes 30, 163–167.

Aregheore, E.M., 1995. Effect of sex on growth rate, voluntary feed intake and nutrient digestibility of West African Dwarf goats fed crop residue rations. Small Rum. Res. 15, 217–221.

Aregheore, E.M., 1996. Voluntary intake and nutrient digestibility of crop-residue based rations by goats and sheep. Small Rum. Res. 22, 7–12.

Aregheore, E.M., 2000. Chemical composition and nutritive value of some tropical by-product feedstuffs for small ruminants – in vivo and in vitro digestibility. Anim. Feed Sci. Technol. 85, 99–109.

Becker, K., Lohrman, J., 1992. Feed selection by goats on tropical semi-humid rangeland. Small Rumin. Res. 8, 285–298.

Bosma, R.H., Bicaba, M.Z., 1997. Effect of addition of leaves from *Combretum aculeatum* and *Leucaena leucocephala* on digestion of sorghum stover by sheep and goats. Small Rum. Res. 24, 167–173.

Carew, B.A.R., 1983. *Gliricidia sepium* as a sole feed for small ruminants. Trop. Grassl. 17, 181–184.

Cheva-Isarakul, B., Rengsirikul, B., 1991. The minimum protein requirement for goats. In: Saithanoo, S., Norton, B.W. (Eds.), Goat Production in the Asian Humid Tropics. The Australian International Development Assistance Bureau, Hat Yai, Thailand, pp. 136–143.

Hadjpanayiotou, M., Hadjidemetriou, D., 1990. Effect of lactation and of roughage to concentrate ratios on outflow rates of protein supplements from the rumen of sheep and goats. Livest. Prod. Sci. 24, 37–46.

Johnson, T.J., Gherardi, S.G., Dhaliwal, S., 1994. Diet quality effects the cashmere production and liveweight of Western Australian cashmere goats. Aust. J. Exp. Agric. 34, 1107–1112.

Kurar, C.K., Mudgal, V.D., 1981. Effect of plane of nutrition on the utilization of dietary energy in dry Beetal goats. Indian J. Anim. Sci. 51, 319–232.

Makembe, N.E.T., Ndlovu, L.R., 1996. Dolichos lablab (*Lab lab purpureus* cv. 'Rongai') as supplementary feed to maize stover for indigenous female goats in Zimbabwe. Small Rum. Res. 21, 31–36.

Ogundola, F.I., 1990. The effect of soyabean meal and groundnut meal supplementation on the growth of West African dwarf goat. World Rev. Anim. Prod. 25, 93–96.

Onwuka, C.F.I., Akinsoyinu, A.O., 1989. Effect of elemental sulphur levels on urea-nitrogen utilization by West African dwarf goats and sheep. Trop. Agric. 66, 158–160.

Pfister, J.A., Malechek, J.C., 1986. The voluntary intake and nutrition of goats and sheep in the semi-arid tropics of Northeastern Brazil. J. Anim. Sci. 63, 1078–1086.

Pralomkarn, W., Kochapakdee, S., Saithanoo, S., Norton, B.W., 1995. Energy and protein utilization for maintenance and growth of Thai native and Anglo-Nubian × Thai native male weaner goats. Small Rum. Res. 16, 13–20.

Rai, S.N., Mudgal, V.D., 1988. Effects of cellulase, alkali and/or steam, treatments of wheat straw on intake, digestibility and balance of minerals in goats. Biol. Wastes 24, 175–185.

Ramirez, R.G., Loyo, A., Mora, R., Sanchez, E.M., Chaire, A., 1991. Forage intake and nutrition of range goats in a shrubland in northeastern Mexico. J. Anim. Sci. 69, 879–885.

Silanikove, N., Gilboa, N., Nitsan, Z., 1997. Interactions among tannins, supplementation and polyethylene glycol in goats given oak leaves: effects on digestion and food intake. Anim. Sci. 64, 479–483.

Srivastave, S.N.L., Sharma, K., 1998. Response of goats to pelleted diet containing different proportions of sun-dried *Leucaena leucocephala*. Small Rum. Res. 28, 139–148.

Wahed, R., Owen, E., Naate, M., Hosking, B.J., 1990. Feeding straw to small ruminants: effect of amount offered on intake and selection of barley straw by goats and sheep. Anim. Prod. 51, 283–289.

References

AFRC, 1993. Energy and Protein Requirements of Ruminants. CAB International, Wallingford, UK, pp. 21–32.

AFRC, 1998. The Nutrition of Goats. CAB International, New York, NY, pp. 41–51.

Akinsoyinu, A.O., 1974. Studies on protein and energy utilization by the West African dwarf goat. Ph.D. Thesis. University of Ibadan, Nigeria.

Al Jassim, R.A.M., Hassan, S.A., Al-Ani, A.N., 1996. Metabolizable energy requirements for maintenance and growth of Awassi lambs. Small Rum. Res. 20, 239–245.

ARC, 1980. The Nutrient Requirements of Ruminant Livestock. Commonwealth Agricultural Bureaux, Slough, UK, pp. 73–119.

Ash, A.J., Norton, B.W., 1987. Studies with the Australian cashmere goat. Part I. Growth and digestion in male and female goats given pelleted diets varying in protein content and energy level. Aust. J. Agric. Res. 38, 957–969.

Beever, D.E., Cammell, S.B., Thomas, C., Spooner, M.C., Haines, M.J., Gales, D.L., 1988. The effects of date of cut and barley substitution on gain and on the efficiency of utilization of grass silage by growing cattle. Part 2. Nutrient supply and energy partition. Br. J. Nutr. 60, 307–319.

Birkelo, C.P., Johnson, D.E., Phetteplace, H.P., 1991. Maintenance requirements of beef cattle as affected by season on different planes of nutrition. J. Anim. Sci. 69, 1214–1222.

Byers, F.M., Schelling, G.T., 1988. Nutrition in growth. In: Church, D.C. (Ed.), The Ruminant Animal: Digestive Physiology and Nutrition. Prentice Hall, Englewood Cliffs, NJ, pp. 437–447.

Chatterjee, S., Hadi, A.S., Price, B., 2000. Regression Analysis by Example, third ed. John Wiley and Sons Inc., New York, NY, pp. 285–312.

Daniel, C., Wood, F.S., 1980. Fitting Equations to Data, second ed. John Wiley and Sons Inc., New York, NY, pp. 19–32.

Dawson, L.E.R., Steen, R.W.J., 1998. Estimation of maintenance energy requirements of beef cattle and sheep. J. Agric. Sci. (Camb.) 131, 477–485.

Early, R.J., Mahgoub, O., Lu, C.D., 2001. Energy and protein utilization for maintenance and growth in Omani ram lambs in hot climates. Part I. Estimates of energy requirements and efficiency. J Agric. Sci. (Camb.) 136, 451–459.

Ferrell, C.L., Koong, L.J., Nienaber, J.A., 1986. Effect of previous nutrition on body composition and maintenance energy costs of growing lambs. Br. J. Nutr. 56, 595–605.

Ferrell, C.L., Jenkins, T.G., 1998a. Body composition and energy utilization by steers of diverse genotypes fed a high-concentrate diet during the finishing period. Part I. Angus, Belgian Blue, Hereford, and Piedmontese sires. J. Anim. Sci. 76, 637–646.

Ferrell, C.L., Jenkins, T.G., 1998b. Body composition and energy utilization by steers of diverse genotypes fed a high-concentrate diet during the finishing period. Part II. Angus, Boran, Brahman, Hereford, and Tuli sires. J. Anim. Sci. 76, 647–657.

Fox, D.G., Black, J.R., 1984. A system for predicting body composition and performance of growing cattle. J. Anim. Sci. 58, 725–739.

Freetly, H.C., Nienaber, J.A., Brown-Brandl, T., 2002. Relationships among heat production, body weight, and age in Finnsheep and Rambouillet ewes. J. Anim. Sci. 80, 825–832.

Freetly, H.C., Nienaber, J.A., Leymaster, K.A., Jenkins, T.G., 1995. Relationships among heat production, body weight, and age in Suffolk and Texel ewes. J. Anim. Sci. 73, 1030–1037.

Garrett, W.N., 1971. Energetic efficiency of beef and dairy steers. J. Anim. Sci. 32, 451–456.

Geay, Y., 1984. Energy and protein utilization in growing cattle. J. Anim. Sci. 58, 766–778.

Graham, N.M., Searle, T.W., Griffiths, D.A., 1974. Basal metabolic rate in lambs and young sheep. Aust. J. Agric. Res. 25, 957–971.

Haaland, G.L., Tyrrell, H.F., Moe, P.W., 1980. The effect of dietary protein and cattle breed on energy utilization for growth. J. Anim. Sci. 51 (Suppl. 1), 365.

Haaland, G.L., Tyrrell, H.F., Moe, P.W., 1981. The effect of dietary protein level and cattle breed on energy utilization of corn-corn silage diets for growth assessed by respiration calorimetry. J. Anim. Sci. 52 (Suppl. 1), 403.

Jagusch, K.T., Duganzich, D.M., Kidd, G.T., Church, S.M., 1983. Efficiency of goat milk utilization by milk-fed kids. NZ J. Agric. Res 26, 443–445.

Johnson, D.E., Larson, E.M., Jarosz, M.J., 1998. Extrapolating from ME to NE: unintended consequences. In: McCracken, K., Unsworth, E.F., Wylie, A.R.G. (Eds.), Energy Metabolism of Farm Animals. CAB International, Cambridge, UK, pp. 383–386.

Kirkland, R.M., Gordon, F.J., 1999. The metabolisable energy requirement for maintenance and the efficiency of use of metabolisable energy for lactation and tissue gain in dairy cows offered a straw/concentrate ration. Livest. Prod. Sci. 61, 23–31.

Kirkpatrick, D.E., Steen, R.W.J., Unsworth, E.F., 1997. The effect of differing forage:concentrate ratio and restricting feed intake on the energy and nitrogen utilization by beef cattle. Livest. Prod. Sci. 51, 151–164.

Kurar, C.K., 1983. Dry matter consumption and its effect on the energy requirements of crossbred (Alpine × Beetal) goats. Indian J. Anim. Sci. 53, 31–35.

Kurar, C.K., Mudgal, V.D., 1981. Effect of plane of nutrition on the utilization of dietary energy in dry Beetal goats. Indian J. Anim. Sci. 51, 319–332.

Lofgreen, G.P., 1965. A comparative slaughter technique for determining net energy values with beef cattle. In: Blaxter, K.L. (Ed.), Energy Metabolism. Academic Press, London, UK, pp. 309–317.

Luo, J., Goetsch, A.L., Nsahlai, I.V., Johnson, Z.B., Sahlu, T., Moore, J.E., Ferrell, C.L., Galyean, M.L., Owens, F.N., 2004. Maintenance energy needs of goats: predictions based on observations of heat and recovered energy. Small Rum. Res. 53, 221–230.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., 1977. Animal Nutrition, second ed. Longman, New York, NY, pp. 262–267.

Moe, P.W., 1981. Energy metabolism of dairy cattle. J. Dairy Sci. 64, 1120–1139.

Montano-Bermudez, M., Nielsen, M.K., Deutscher, G.H., 1990. Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. J. Anim. Sci. 68, 2279–2288.

Montgomery, D.C., Peck, E.A., 1982. Introduction to Linear Regression Analysis. John Wiley and Sons Inc., New York, NY, pp. 430–437.

Moore, J.E., Brant, M.H., Kunkle, W.E., Hopkins, D.I., 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. J. Anim. Sci. 77 (Suppl. 2), 122–135.

NRC, 1981. Nutrient Requirements of Goats: Angora, Dairy, and Meat Goats in: Temperate and Tropical Countries. National Academy Press, Washington, DC, pp. 2–3.

NRC, 1984. Nutrient Requirements of Beef Cattle, sixth ed. National Academy Press, Washington, DC, pp. 47–61.

NRC, 1985. Nutrient Requirements of Sheep, sixth revised ed. National Academy Press, Washington, DC, pp. 4–5.

Onwuka, C.F.I., Akinsoyinu, A.O., 1989. Protein and energy requirements for maintenance and gain by West African Dwarf Goats fed cassava (*Manihot utilissima*) leaves with peels as supplement. Small Rum. Res. 2, 291–298.

Pralomkarn, W., Kochapakdee, S., Saithanoo, S., Norton, B.W., 1995. Energy and protein utilization for maintenance and growth of Thai native and Anglo-Nubian × Thai native male weaner goats. Small Rum. Res. 16, 13–20.

Rajpoot, R.L., 1979. Energy and protein in goat nutrition. Ph.D. Thesis. Raja Balwant Singh College, Bichpuri, Agra, India.

Reid, C.R., Bailey, C.M., Judkins, M.B., 1991. Metabolizable energy for maintenance of beef-type *Bos taurus* and *Bos indicus* × *Bos taurus* cows in a dry, temperate climate. J. Anim. Sci. 69, 2779–2786.

Rohr, K., Daenicke, R., 1984. Nutritional effects on the distribution of live weight as gastrointestinal tract fill and tissue components in growing cattle. J. Anim. Sci. 58, 753–765.

Sanz Sampelayo, M.R., Lara, L., Gil Extremera, F., Boza, J., 1995. Energy utilization for maintenance and growth in preruminant kid goats and lambs. Small Rum. Res. 17, 25–30.

Sanz Sampelayo, M.R., Munoz, F.J., Guerrero, J.E., Gil Extremera, F., Boza, J., 1988. Energy metabolism of the Granadina breed goat kid: use of goat milk and a milk replacer. J. Anim. Physiol. Anim. Nutr. 59, 1–9.

SAS, 1990. SAS User's Guide: Statistics, sixth ed. SAS Inst. Inc., Cary, NC.

SCARM, 1994. Feeding Standards for Australian Livestock: Ruminants. CSIRO, Victoria, Australia, pp. 40–41, 51–53, 233–234.

Snedecor, G.W., Cochran, W.G., 1978. Statistical Methods, sixth ed. The Iowa State University Press, Ames, IA, pp. 419–446.

Solis, J.C., Byers, F.M., Schelling, G.T., Long, C.R., Greene, L.W., 1988. Maintenance requirements and energetic efficiency of cows of different breed types. J. Anim. Sci. 66, 764–773.

Steen, R.W.J., Dawson, L.E.R., Kirkpatrick, D.E., Johnston, S.D., 1998. Estimation of maintenance energy requirements and efficiency of utilization of metabolizable energy for growth in lambs by indirect calorimetry and comparative slaughter. In: McCracken, K., Unsworth, E.F., Wylie, A.R.G. (Eds.), Energy Metabolism of Farm Animals, CAB International, Cambridge, UK, pp. 351–354.

Tyrrell, H.F., Moe, P.W., 1980. Energetics of growth in cattle. In: Mount, L.E. (Ed.), Energy Metabolism. EAAP Publ. No. 26, Butterworth Inc., Woburn, MA, pp. 227–229.

Unsworth, E.F., McCrachen, K.J., Moore, C.A., Steen, R.W.J., Kilpatrick, D.J., 1991. Energy retention in steers as measured by respiration calorimetry and carcass composition. In: Wenk, C., Boessinger, M. (Eds.), Energy Metabolism of Farm Animals. EAAP Publ. No. 58, Hartause Ittingen, Switzerland, pp. 190–193.

Van Soest, P.J., 1994. Nutritional Ecology of the Ruminant, second ed. Cornell University Press, Ithaca, NY, pp. 345–349.

Webster, A.J.F., 1981. The energetic efficiency of metabolism. Proc. Nutr. Soc. 40, 121–128.

Webster, A.J.F., Brockway, J.M., Smith, J.S., 1974. Energy exchanges during growth in cattle. In: Menke, K.H., Lantsch, H.J., Reichl, J.R. (Eds.), Energy Metabolism of Farm Animals, EAAP Publ. No. 14. Stuttgart, Germany, pp. 135–138.

Yan, T., Gordon, F.J., Agnew, R.E., Porter, M.G., 1998. The metabolizable energy requirement for maintenance and the efficiencies of utilization of metabolizable energy for lactation and tissue retention in dairy cows. In: McCracken, K., Unsworth, E.F., Wylie, A.R.G. (Eds.), Energy Metabolism of Farm Animals. CAB International, Cambridge, UK, pp. 97–100.

Zemmelink, G., Tolkamp, B.J., Meinderts, J.H., 1985. Feed intake and weight gain of West African dwarf goats. In: Sumberg, J.E., Cassaday, K. (Eds.), Sheep and Goats in Humid West Africa. Int. Livest. Center for Africa, Addis Ababa, Ethiopia, pp. 29–33.

Zemmelink, G., Tolkamp, B.J., Ogink, N.M.W., 1991. Energy requirements for maintenance and gain of West African Dwarf goats. Small Rum. Res. 5, 205–215.