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Prediction of metabolizable energy and protein requirements for maintenance, gain and fiber growth of Angora goats

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Abstract

A database was constructed for growing and mature Angora goats to estimate metabolizable energy (ME) and protein (MP) requirements for maintenance, whole BW gain (ADG), non-fiber tissue gain (TG) and fiber growth (clean fiber growth rate; CFGR). MP intake (MPI) was calculated from CP degradability properties and dietary proportions of feedstuffs. Variables, scaled by $BW^{0.75}$, consisted of mean BW (kg), ME intake (MEI; kJ per day), MPI (g per day), ADG (g per day), TG (g per day; i.e., ADG corrected for grease fiber) and CFGR (g per day). For ME, the final simple regression equation for mature goats was MEI = 533 (SE = 18.8) + (43.2 (SE = 4.77) × ADG) ($n = 77$; $R^2 = 0.52$). The final multiple regression equation for mature goats was MEI = 473 (SE = 49.85) + (37.2 (SE = 6.97) × TG) + (157 (SE = 52.5) × CFGR) ($n = 48$; $R^2 = 0.53$). For MP, the final simple regression equation with a development data set for growing and mature goats was MPI = 4.30 (SE = 0.286) + (0.318 (SE = 0.0471) × ADG) ($n = 68$; $R^2 = 0.41$), which resulted in unbiased prediction of MPI in an evaluation data set. The final multiple regression equation for growing and mature goats was MPI = 3.35 (SE = 0.440) + (0.281 (SE = 0.0486) × TG) + (1.65 (SE = 0.394) × CFGR) ($n = 83$; $R^2 = 0.46$). In conclusion, ME requirements of mature Angora goats for maintenance, TG and CFGR were 473 kJ/kg $BW^{0.75}$, 37.2 and 157 kJ/g (113 kcal/kg $BW^{0.75}$, 8.89 and 37.5 kcal/g), respectively. MP requirements of growing and mature Angora goats for maintenance, TG and CFGR were 3.35 g/kg $BW^{0.75}$, 0.281 and 1.65 g/g, respectively.

Keywords: ME requirements; MP requirements; Mohair; Angora goats

1. Introduction

Mohair production by Angora goats is an important livestock enterprise in some parts of the world. Nonetheless, energy and protein needs of Angora

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goats have not been well defined. Recommendations of NRC (1981) for fiber production requirements of Angora goats were based only on predictions of Huston et al. (1971) and an assumed maintenance requirement similar to other goats. Likewise, AFRC (1998) recommended similar maintenance energy and protein requirements for Angora as for other goats, and calculated metabolizable energy (ME) and metabolizable protein (MP) requirements for fiber production from sheep data. However, there has been appreciable research conducted in the last two decades on nutritional needs of Angora goats that has not yet been compiled (e.g., Sahlu et al., 1992; Reis and Sahlu, 1994; Herselman et al., 1998; Toerien et al., 1999). Hence, in the present study, data from feeding and nutrition experiments conducted from 1972 to 2001 were used to predict ME and MP requirements for maintenance, whole BW gain, non-fiber tissue gain and mohair fiber growth of Angora goats.

2. Materials and methods

2.1. Database construction and prediction of ME requirements

2.1.1. Database construction

The preliminary database was derived from 55 publications or reports involving 222 treatment mean observations and representing 2105 Angora goats or Angora crossbreds (≥50% Angora), with experiments averaging 69 days in length (12–128 days). ME intake (MEI; kJ per day), CP intake (CPI; g per day) and mean BW (kg) were reported or could be calculated for all reports. For 15 reports (81 treatment means), dietary ME concentration was estimated from dietary proportions of feedstuffs and published ME or total digestible nutrient concentrations in contributing feedstuffs (NRC, 1981, 1984). Goats were classified into five physiological states: lactating, pregnant, mature (≥12 months of age, wethers and dry does, not pregnant), growing (weaning to 12 months of age) or preweaning. However, because of potential differences in nutrient requirements among physiological states and low numbers of treatment mean observations, data for preweaning (four observations), pregnant (one observation) and lactating (seven observations) goats were omitted; therefore, only data for growing and mature Angora goats were used.

Database 1 included 144 treatment means from 33 reports (citations presented in Appendix A) and represented 1580 goats in which BW change was available. ADG (g per day) represented total or whole BW change, both tissue and fiber. For database 2, there were 105 treatment means of database 1 for which both ADG and clean fiber growth rate (CFGR) were measured or calculated. Thirty-one of the observations entailed calculation of clean fiber growth rate (g per day) from clean fiber weight measured by the mid-side patch method as described by Puchala et al. (2001). Non-fiber tissue gain (TG) was derived by subtracting grease fiber growth rate (GFGR; g per day) from ADG, with GFGR estimated from CFGR using a regression equation (GFGR $= 1.373 \times$ CFGR; $n = 397$, $R^2 = 0.99$) based on Angora goat performance test data over a 6-year period (1997–2002; Waldron, 2002). After examining all observations, 16 treatment means from four publications with unusually high CFGR compared with other studies in the database (18.9 g per day versus 12.6 g per day) or very high variation within report in CFGR were excluded; therefore, the resultant database 2 consisted of 89 observations from 20 publications and represented 1109 goats. Databases 1 and 2 were used for simple and multiple linear regression analyses, respectively.

2.1.2. ME requirements with simple linear and multiple regression analyses

Variables were scaled by $BW^{0.75}$ (Luo et al., 2004b). Metabolizable energy intake (MEI) and metabolizable protein intake (MPI) were regressed against ADG (simple linear) and TG and CFGR (multiple). Initial regressions were conducted to test for differences between physiological states in intercepts and slopes by analysis of covariance (Snedecor and Cochran, 1978) using PROC GLM of SAS (1990). This model consisted of the fixed effect of physiological state, ADG and the interaction between physiological state and ADG. The corresponding model for multiple linear regression included physiological state, TG, CFGR and interactions between physiological state and TG and CFGR. For both simple and multiple regressions, intercepts and regression coefficients for growing and mature goats were different (simple regression: $P < 0.01$ for the intercept and slope; multiple regression:

Table 1
Summary of data sets for growing and mature Angora goats of database 1 for prediction of ME requirements for maintenance and ADG by simple linear regression

Variable	Growing[a] Angora goats					Mature Angora goats				
	n	Mean	S.D.	Minimum	Maximum	n	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	65	22.4	4.26	15.6	29.9	79	33.1	10	17.1	57.6
CP (%DM)	65	13.9	3.45	7	31.1	79	13.2	3.19	4.81	22.7
Forage (%DM)	57	46.8	22.65	0	100	77	52.6	17.03	30	100
DM intake (kg per day)	65	0.812	0.2255	0.479	1.457	79	0.889	0.221	0.298	1.508
ME intake (MJ per day)	65	8.03	0.211	4.22	13.96	79	8.62	0.229	3.4	15.55
ME intake (MJ/kg BW$^{0.75}$ day)	65	0.779	0.1496	0.446	1.291	79	0.647	0.1713	0.263	1.014
ADG (g per day)	65	74.1	39.49	1.9	163.4	79	35.4	32.88	−73.2	99.6
ADG (g/kg BW$^{0.75}$ day)	65	7.12	3.449	0.22	14.45	79	2.81	2.799	−6.36	9.77
Clean fleece growth rate (g per day)	46	12.4	3.88	6.1	24.3	59	13.3	4.56	4.8	27.6
Clean fleece growth rate (g/kg BW$^{0.75}$ day)	46	1.16	0.312	0.61	1.96	59	1.04	0.463	0.36	2.71

1 Mcal = 4.184 MJ.
[a] Less than 1 year of age.

$P = 0.02$, 0.05 and 0.08 for the intercept and coefficients for TG and CFGR, respectively); thus, separate regressions were conducted.

Database 1 (Table 1) included 65 and 79 observations for growing and mature goats and database 2 (Table 2) entailed 40 and 49 observations for growing and mature goats, respectively. Due to limited numbers of observations, data sets for growing and mature goats of the databases were not split into separate sets for equation development and evaluation. Preceding simple linear regressions, linear, quadratic and cubic effects of ADG on MEI were checked to justify the use of only the linear effect of ADG. A cubic effect was thought deserved of evaluation because of potential use of mobilized tissue to support mohair fiber growth with low MEI and also different levels of MEI at which tissue gain and fiber growth might be maximized. As described by Luo et al. (2004a), some observations were removed to increase explained variation, so that best predictions possible could be achieved for the majority of populations. Briefly, the residual for each observation was compared with various multiples of the residual S.D. (R.S.D.), and observations with differences greater than selected R.S.D. were removed and changes in regression R^2 and root mean square error (RMSE) were viewed. The R.S.D. used to exclude observations was chosen on the basis of a moderate to appreciable increase in explained variability, while

Table 2
Summary of data sets for growing and mature Angora goats of database 2 for prediction of ME requirements for maintenance, tissue gain and clean fiber growth rate by multiple regression

Variable	Growing[a] Angora goats					Mature Angora goats				
	n	Mean	S.D.	Minimum	Maximum	n	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	40	22.8	4.21	16.1	29.2	49	32.4	8.54	17.1	47.5
CP (%DM)	40	13.1	3.09	7	17.8	49	13.4	2.68	9.1	22.7
Forage (%DM)	36	54.9	19.83	0	100	47	48	14.36	30	87
DM intake (kg per day)	40	0.871	0.2153	0.518	1.457	49	0.864	0.2322	0.298	1.45
ME intake (MJ per day)	40	8.25	1.862	5.46	13.21	49	8.73	0.239	3.4	14
ME intake (MJ/kg BW$^{0.75}$ day)	40	0.791	0.1231	0.585	1.052	49	0.656	0.1534	0.295	0.974
Tissue gain (g per day)	40	58.2	42.05	−10.0	138.5	49	13.6	30.34	−79.8	66.8
Tissue gain (g/kg BW$^{0.75}$ day)	40	5.42	3.705	−1.17	13.15	49	1.13	2.391	−6.94	5.25
Clean fleece growth rate (g per day)	40	12.6	4.01	6.1	24.3	49	12.4	4.03	4.8	18.4
Clean fleece growth rate (g/kg BW$^{0.75}$ day)	40	1.20	0.305	0.67	1.96	49	0.934	0.3104	0.36	1.854

1 Mcal = 4.184 MJ.
[a] Less than 1 year of age.

retaining the maximum number of observations. Observations removed from the subset were examined in detail for each computation (Chatterjee et al., 2000).

2.1.3. ME requirements with a factorial approach

In addition to simple and multiple regression analyses that provide estimates of the ME requirement for maintenance (ME_m), ME requirements for ADG and CFGR were also determined with a factorial approach. It was assumed that ME_m was 462 kJ/BW$^{0.75}$ (Luo et al., 2004c); therefore, MEI available for ADG (MEI_g) was the difference between MEI and ME_m. The ME requirement for ADG (ME_g) was estimated as the slope of the regression of MEI_g against ADG with database 1. Variables were unscaled or scaled by BW$^{0.75}$.

For observations in database 2, in addition to the aforementioned ME_m assumption, an ME requirement for tissue gain (ME_{tg}) for mature goats of 28.5 kJ/g (Luo et al., 2004c) was employed to estimate MEI used for CFGR (MEI_f). This ME_{tg} was used since others determined specifically with Angora goats were not available. Though none developed with goats is available, use of an equation to predict energy concentration in tissue gain dependent upon BW or stage of maturity might have more appropriately addressed potential differences between growing and mature Angoras but would necessitate an assumption of the efficiency of ME use for tissue energy accretion. Furthermore, the assumed constant ME_{tg} may infer increasing efficiency of energy use in tissue gain as energy concentration in accreted tissue increases with increasing fat deposition and decreasing protein accretion as animals mature (Tolkamp and Ketelaars, 1992). MEI_f was derived by subtracting ME_m and MEI_{tg} from MEI. The regression of MEI_f against CFGR provided an estimate of the ME requirement for fiber growth of Angora goats (ME_f). As noted before, different BW scaling methods were tested.

2.2. Database construction and prediction of MP requirements

2.2.1. Database construction and MP intake calculation

In database 1, data from 26 publications, consisting of 124 treatment means and representing 1089 goats, were used to form database 3 for estimating MP intake (MPI) generally as described by Nsahlai et al. (2004). Briefly, a parallel database of CP degradability properties for dietary ingredients was constructed. When not provided in the original publication, published CP concentrations of feedstuffs were used (AFRC, 1993; NRC, 2001). CP degradability properties included soluble CP (SolP), soluble nonprotein N or CP as a percentage of SolP (SolNP), insoluble protein that can be potentially degraded slowly in the rumen and is available for digestion in the small intestine (SDP), rate of degradation of SDP ($Rate_{SDP}$) and acid detergent insoluble protein (ADIP; indigestible in the rumen and intestines). SolP is described by NRC (2001) as nonprotein N assumed to be instantly degraded in the rumen and true protein that rapidly escapes from in situ bags because of high solubility or very small particle size, comparable to the quickly degraded CP fraction of AFRC (1993). Soluble true protein was estimated as the difference between SolP and SolNP. The SDP fraction is comparable to the B fraction listed by AFRC (1993) and NRC (2001; presented in tabular form). A fraction of insoluble protein not subject to ruminal degradation but potentially degraded in the small intestine (rumen undegraded but intestinally digestible dietary protein; RUDDP) was calculated as the difference between total CP and the sum of SolP, SDP and ADIP. Sources of feedstuff CP degradability properties were primarily derived from NRC (2000) for SolP and SolNP; NRC (2001) and AFRC (1993) for SDP and $Rate_{SDP}$; and NRC (2001), AFRC (1993) and NRC (2000) for ADIP, with an additional small number of listings derived from INRA (1989) when not available from other sources. It was assumed that all urea CP in urea-treated wheat straw was soluble in acid detergent solution to calculate ADIP. Dietary levels of the different CP fractions and $Rate_{SDP}$ were based on values and dietary proportions of individual feedstuffs.

Level of feeding (L) was defined as ME intake divided by the ME requirement for maintenance (ME_m). An ME_m (kJ/kg BW$^{0.75}$) of 315k_m was assumed based on AFRC (1998) recommendations for the net energy for maintenance requirement of 315 kJ/kg BW$^{0.75}$ and efficiency of ME utilization for maintenance ($k_m = 0.503 + (0.019 \times \mathrm{ME})$; MJ/kg DM). Energy costs for activity were not considered.

SolNP was assumed completely degraded in the rumen (AFRC, 1993); thus, the extent of ruminal degradation of SolNP (ExSolNP) was equal to SolNP. Because it has not been clearly established how rates of digesta passage from the rumen of goats compare with other ruminant species, the extent of ruminal protein digestion was based in part on estimates of fluid and particulate passage rates. Ruminal outflow rate of particulates (k_p) was estimated following the equation proposed by AFRC (1993): $k_p = -0.024 + 0.179(1 - e^{-0.278L})$. Based on Nsahlai et al. (1999), ruminal fluid dilution rate (k_l) was determined as a function of k_p: $k_l = (k_p - 0.0018)/0.360$. With an approach similar to that of Ngwa et al. (2001), passage rates were used to determine the extent of ruminal degradation of SolTP (ExSolTP) and SDP (ExSDP):

$$\text{ExSolTP} = \frac{\text{SolTP} \times \text{Rate}_{\text{SolTP}}}{\text{Rate}_{\text{SolTP}} + k_l} \quad \text{and}$$

$$\text{ExSDP} = \frac{\text{SDP} \times \text{Rate}_{\text{SDP}}}{\text{Rate}_{\text{SDP}} + k_p}$$

where $\text{Rate}_{\text{SolTP}}$ is the rate of degradation of SolTP. In vitro ammonia accumulation (y) data of Brown et al. (1998) for casein were used to derive the equation:

$$y = 2.75\,(\text{SE} = 0.537) + 9.88\,(\text{SE} = 1.101)(1 - e^{-0.084\,(\text{SE}=0.0265)\times \text{time}}) \quad (R^2 = 0.98;\ n = 7)$$

Thus, $\text{Rate}_{\text{SolTP}}$ was 0.084. Undegraded SolTP and SDP were calculated by difference. Total undegraded protein in the rumen (RUDP) was obtained by summing undegraded SolTP and SDP and RUDDP, which was assumed to be 0.90 digestible postruminally (AFRC, 1993) to obtain digestible undegraded protein (DUDP).

AFRC (1993) assumed efficiencies of capture of N in ExSolNP and ExSolTP for microbial protein (MicP) synthesis of 0.8 and in ExSDP of 1.0. Hence, effective capture ruminally degraded CP (ERDP) was the sum of 0.8 × SolNP, 0.8 × ExSolTP and 1.0 × ExSDP. Furthermore, because utilization of ERDP in microbial CP synthesis depends on energy availability, energy from ruminal fermentation (RFE) was derived from listings in Appendix A of AFRC (1993) of ME and RFE contents of dietary concentrates and forages. Means of RFE were 0.926 (n = 11; S.D. = 0.0435) and 0.820 (n = 18; SE = 0.0275) for forage and concentrate ME, respectively. These estimates were used along with ME intake and dietary concentrate and forage proportions to estimate RFE (MJ). Using the equation proposed by AFRC (1993), microbial protein was estimated for conditions with adequate ruminal availability of nitrogenous compounds as

$$\text{MicP (g)} = (7 + 6(1 - e^{-0.35L})) \times \text{RFE}$$

In accordance with ARC (1980), when the RFE-based estimate of MicP was greater than ERDP, ruminal availability of nitrogenous compounds was assumed limiting and, thus, MicP was set equal to ERDP. Assuming MicP N to be 0.25 nucleic acid N and that microbial true protein is 0.85 digestible in the small intestine, digestible microbial true protein (DMTP) was estimated as 0.6375 × MicP (AFRC, 1993). MPI was derived by adding DUDP and DMTP. Variables of database 3 are summarized in Table 3.

Based on database 3, database 4 was formed with observations for which CFGR was reported or could be calculated in order to estimate MP requirements for maintenance (MP_m), tissue gain (MP_tg) and fiber growth (MP_f) with multiple linear regression analysis. Database 4 included 88 treatment means and represented 776 goats, with variables summarized in Table 4.

2.2.2. MP requirements with simple linear regression

Preceding simple regression analysis, analysis of covariance using GLM procedures of SAS (1990) was performed to test for differences in intercepts and slopes between growing and mature goats. Because differences were not significant ($P = 0.43$ and 0.47 for intercepts and slopes, respectively), data were pooled. Database 4 was then split, using publication or reference as the basis, into development and evaluation data sets as described by Luo et al. (2004a). However, because homogenous data sets could not be obtained by this approach, the database was split by treatment mean observation. Means, S.D. and the range in means for development and evaluation data sets are presented in Table 5. Using the development data set, there were no differences between growing and mature goats in intercepts or slopes ($P = 0.30$ and 0.98, respectively) of regressions of MPI against ADG, thereby justifying use of pooled data. In addition, quadratic and cubic effects of ADG in regressions of MPI were checked, as described for MEI, and were found nonsignificant

Table 3
Summary of database 3 for predicting metabolizable protein requirements for maintenance and ADG of Angora goats

Variable	*n*	Mean	S.D.	Minimum	Maximum
Soluble CP (g/g total CP)	124	0.314	0.0764	0.122	0.523
Soluble nonprotein CP (g/g soluble CP)	124	0.544	0.2506	0.108	0.933
Slowly degradable protein (SDP; g/g total CP)	124	0.593	0.0862	0.34	0.794
Rate of SDP degradation (h^{-1})	124	0.096	0.0597	0.026	0.311
Acid detergent insoluble CP (g/g total CP)	124	0.061	0.0378	0.02	0.243
DRUDP[a] (g/g total CP)	124	0.042	0.0428	0	0.21
Mean BW (kg)	124	27.9	8.57	15.6	57.6
Forage (%DM)	120	47.7	15.96	0	87
CP (%DM)	124	13.7	3.15	9.1	31.1
ME (MJ/kg DM)	124	9.79	1.542	4.66	13.3
DM intake (kg per day)	124	0.848	0.2298	0.298	1.457
ME intake (MJ per day)	124	8.37	2.176	3.4	14
ME intake (MJ/kg $BW^{0.75}$ day)	124	0.709	0.1675	0.295	1.291
ADG (g per day)	124	54.7	39.9	−73.2	163.4
ADG (g/kg $BW^{0.75}$ day)	124	4.93	3.687	−6.36	13.73
CP intake (g per day)	124	117	41.5	32	274
CP intake (g/kg $BW^{0.75}$ day)	124	9.86	3.141	2.77	19.26
DRUDP intake (g per day)	124	5.48	6.919	0	33.51
Total digestible ruminally undegraded protein intake[b] (g per day)	124	32.7	17.4	2.5	100
Microbial CP (g per day)	124	62.1	17.67	24	118.1
Metabolizable protein intake (g per day)	124	72.3	26.94	17.8	167.9
Metabolizable protein intake (g/kg $BW^{0.75}$ day)	124	6.16	2.148	1.55	12.98

1 Mcal = 4.184 MJ.
[a] DRUDP = ruminally undegradable but intestinally digestible protein.
[b] Sum of DRUDP and ruminally undegraded soluble CP and insoluble true protein.

Table 4
Summary of database 4 for prediction of the metabolizable protein requirements for maintenance, non-fiber tissue gain and fiber growth of Angora goats

Variable	*n*	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	88	28.7	7.61	16.1	45.7
Forage (%DM)	84	50	12.43	30	87
CP (%DM)	88	13.5	2.97	9.1	22.7
ME (MJ/kg DM)	88	9.73	0.129	4.66	11.9
DM intake (kg per day)	88	0.852	0.2211	0.298	1.457
ADG (g per day)	88	53.1	42.32	−73.2	163.4
ADG (g/kg $BW^{0.75}$ day)	88	4.58	3.718	−6.36	13.73
Clean fleece growth rate (g per day)	88	12.9	4.69	4.8	27.6
Clean fleece growth rate (g/kg $BW^{0.75}$ day)	88	1.07	0.437	0.407	2.711
Tissue gain[a] (g per day)	88	35.3	40.59	−79.8	138.5
Tissue gain (g/kg $BW^{0.75}$ day)	88	3.11	3.49	−6.94	11.81
CP intake (g per day)	88	117	44.3	32	274
CP intake (g/kg $BW^{0.75}$ day)	88	9.57	3.243	2.77	19.26
Metabolizable protein intake (g per day)	88	74.2	28.36	17.8	167.9
Metabolizable protein intake (g/kg $BW^{0.75}$ day)	88	6.13	2.141	1.55	12.98

1 Mcal = 4.184 MJ.
[a] Tissue gain was corrected for grease fleece weight, which was estimated from clean fiber weight.

Table 5
Summary of development and evaluation data sets of database 3 for prediction of metabolizable protein requirements for maintenance, ADG, non-fiber tissue gain and fiber growth of Angora goats

Variable	Development[a]					Evaluation[b]				
	n	Mean	S.D.	Minimum	Maximum	*n*	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	73	28.5	8.44	15.6	57.6	51	27.1	8.76	15.6	45.7
DM intake (kg per day)	73	0.853	0.2306	0.298	1.45	51	0.842	0.2308	0.5	1.457
CP (%DM)	73	13.8	3.54	9.1	31.1	51	13.6	2.52	9.2	22.7
Forage (%DM)	70	46	15.96	0	78.7	50	50	15.84	12	87
CP intake (g per day)	73	118	43	32	274	51	116	39.6	47	242
ADG (g per day)	73	55	40.07	−73.2	163.4	51	54.2	40.1	−35.4	163.4
ADG (g/kg $BW^{0.75}$ day)	73	4.89	3.733	−6.36	13.21	51	4.98	3.657	−2.21	13.73
MP intake (g per day)	73	73.6	27.37	17.8	167.9	51	70.6	26.49	28.5	139
MP intake (g/kg $BW^{0.75}$ day)	73	6.16	2.183	1.55	12.98	51	6.16	2.118	2.33	11.07
Clean fleece growth rate (g per day)	47	13.6	4.87	4.8	27.6	41	12.1	4.38	5.2	21.4
Clean fleece growth rate (g/kg $BW^{0.75}$ day)	47	1.12	0.492	0.42	2.71	41	1.02	0.363	0.41	2.15

[a] Used to develop prediction equations.
[b] Used to evaluate prediction equations.

($P = 0.22$ and 0.15, respectively), but the linear effect was significant ($P = 0.007$). Hence, the simple linear regression model was used in the analysis. After removal of some observations as noted above for ME, the final equation from the development data set was used to predict MPI in the evaluation data set. Observed values were regressed against predictions to determine whether the intercept and slope differed from 0 and 1, respectively.

2.2.3. MP requirements with multiple regression analysis

Preceding multiple regression analyses, differences between growing and mature goats in intercepts and partial regression coefficients of regressions of MPI against TG and CFGR were tested by analysis of covariance using GLM procedures of SAS (1990). *P* values were 0.40 for the intercept and 0.35 and 0.06 for TG and CFGR coefficients, respectively; therefore, data were pooled. There were significant linear effects of TG ($P < 0.01$) and CFGR ($P = 0.04$) on MPI. Residuals of MPI were examined as noted earlier to improve fit of the model.

2.3. MP requirements with a factorial approach

Similar to estimation of ME requirements, a factorial approach was used for MP. The net protein requirement for maintenance (NP_m) included endogenous urinary CP (EUCP), metabolic fecal CP (MFCP) and scurf CP losses (SCP). EUCP was assumed to be 1.031 g/kg $BW^{0.75}$ (Luo et al., 2004b), and MFCP was 2.67% of DM intake (Moore et al., 2004). The estimate of SCP of 0.2 g/kg $BW^{0.6}$ of NRC (1984) was also employed. The sum of EUCP, MFCP and SCP was converted to MP_m with efficiencies of MP use for maintenance (k_{pm}) of 0.67 (NRC, 2001) and 1.00 (AFRC, 1993). MPI available for ADG (MPI_g) was obtained as the difference between MPI and MP_m. It appeared that the k_{pm} of 0.67 overestimated MP_m and thus underestimated MPI_g; therefore, the k_{pm} of 1.00 (AFRC, 1993) was used to calculate MP_m. MPI_g was regressed against ADG with variables unscaled or scaled by $BW^{0.75}$.

For observations in database 4, to calculate the tissue protein content it was assumed that the protein content of empty BW gain was 16% (AFRC, 1998). Concentrations of empty BW gain components were converted to a live BW basis by dividing by 1.09 (ARC, 1980), resulting in a protein concentration in live BW gain of 14.7%. Protein accreted in tissue gain (NP_{tg}) was the product of TG and protein concentration in live BW gain. The MP requirement for tissue gain (MP_{tg}) was calculated assuming an efficiency of MP use for growth (k_{tg}) of 0.59 (AFRC, 1998). MPI_{tg} was estimated as the product of TG and MP_{tg}. Thus, MPI used for fiber growth (MPI_f) was calculated as $MPI - (MP_m + MPI_{tg})$. MPI_f was regressed against CFGR, again with different scaling methods.

3. Results

3.1. ME

3.1.1. ME requirements for maintenance and whole BW gain—simple linear regression

With the data set for growing Angora goats, linear, quadratic and cubic effects of ADG on MEI were not significant ($P = 0.74$, 0.52 and 0.55, respectively), which might be ascribed to the limited number of observations or variable capacity for TG by growing Angora goats used in the experiments. Nonetheless, the equation for the linear regression of MEI (kJ/kg $BW^{0.75}$) against ADG (g/kg $BW^{0.75}$) was

$$\mathrm{MEI} = 662\,(\mathrm{SE} = 40.0) + (16.4\,(\mathrm{SE} = 5.06) \times \mathrm{ADG}) \quad (n = 65;\ R^2 = 0.14) \tag{1}$$

With the data set for mature Angora goats, quadratic and cubic effects of ADG on MEI were not significant ($P = 0.96$ and 0.97, respectively). Regressing MEI against ADG alone produced the following equation:

$$\mathrm{MEI} = 527\,(\mathrm{SE} = 19.7) + (42.8\,(\mathrm{SE} = 4.98) \times \mathrm{ADG}) \quad (n = 79;\ R^2 = 0.49) \tag{2}$$

The final equation, after removing two observations with residuals greater than 2.0 R.S.D., was

$$\mathrm{MEI} = 533\,(\mathrm{SE} = 18.8) + (43.2\,(\mathrm{SE} = 4.77) \times \mathrm{ADG}) \quad (n = 77;\ R^2 = 0.52) \tag{3}$$

Regression lines for Eqs. (2) and (3) are presented in Fig. 1. There was no apparent reason for large residuals of the removed observations, such as dissimilar BW, ADG, fiber growth or dietary levels of forage, ME or CP relative to other observations. Based on Eq. (3), estimates of ME_m (including the energy cost for activity in pen or stall settings) and ME_g were 533 kJ/kg $BW^{0.75}$ and 43.2 kJ/g ADG, respectively.

3.1.2. ME requirements for maintenance, tissue gain and fiber growth—multiple regression

The equation for the multiple regression of MEI against TG and CFGR for mature Angora goats in database 2 was

$$\mathrm{MEI} = 469\,(\mathrm{SE} = 52.3) + (33.6\,(\mathrm{SE} = 7.15) \times \mathrm{TG}) + (159\,(\mathrm{SE} = 55.1) \times \mathrm{CFGR}) \quad (n = 49;\ R^2 = 0.47) \tag{4}$$

A corresponding equation for growing goats was not presented because of the low coefficient of determination and a nonsignificant CFGR regression coefficient, which could be attributable to the limited number of observations in the data set. With the same equation examination process used for mature Angoras, one observation with a residual greater than 2.0 S.D. was removed, and the following equation, depicted in Fig. 2, was derived:

$$\mathrm{MEI} = 473\,(\mathrm{SE} = 49.9) + (37.2\,(\mathrm{SE} = 6.97) \times \mathrm{TG}) + (157\,(\mathrm{SE} = 52.5) \times \mathrm{CFGR}) \quad (n = 48;\ R^2 = 0.53) \tag{5}$$

Standardized partial regression coefficients indicated that 64 and 36% of explained variability was attributable to TG and CFGR, respectively. The ME_m from Eq. (5) was 473 kJ/kg $BW^{0.75}$, which was not different ($P = 0.23$) from that of Eq. (3) (i.e., 533 kJ/$kg^{0.75}$). ME_{tg} was 37.2 kJ/g and ME_f was 157 kJ/g of clean fiber.

3.1.3. ME requirements for whole BW gain and fiber growth—factorial approach

With the mature Angora goat data set used for Eq. (3) (from database 1), regressing partitioned MEI_g against ADG resulted in the following equations:

unscaled :

$$\mathrm{MEI_g} = 864\,(\mathrm{SE} = 256.6) + (43.7\,(\mathrm{SE} = 5.38) \times \mathrm{ADG}) \quad (n = 77;\ R^2 = 0.47)$$

scaled by $BW^{0.75}$:

$$\mathrm{MEI_g} = 71.0\,(\mathrm{SE} = 18.83) + (43.2\,(\mathrm{SE} = 4.77) \times \mathrm{ADG}) \quad (n = 77;\ R^2 = 0.52)$$

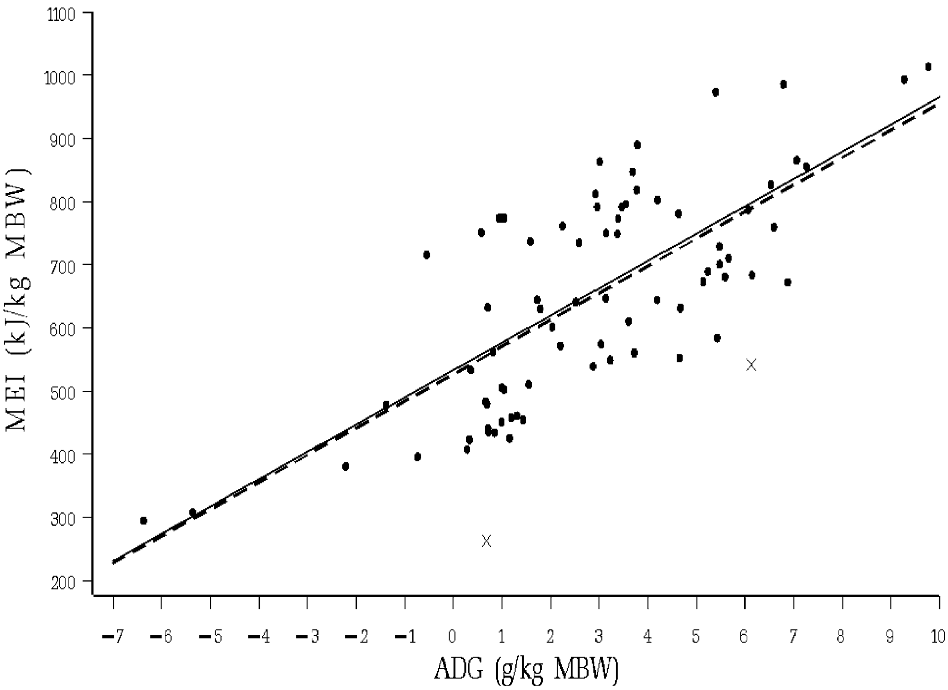

Fig. 1. Relationship between ME intake (kJ/kg$^{0.75}$) and ADG (g/kg$^{0.75}$) of mature Angora goats. Points are observed values, the dashed line (---) represents the regression line for all observations in the data set and the solid line (—) is for the regression after removal of observations with high residuals (×: observations removed) and describes the equation: MEI = 533 (SE = 18.8) + (43.2 (SE = 4.77) × ADG) ($n = 77$; $R^2 = 0.52$). MBW = kg BW$^{0.75}$.

ME_g was similar regardless of scaling, although the SE of the regression coefficient was lowest and the R^2 was highest for BW$^{0.75}$. However, the intercept of each equation differed from 0 ($P = 0.01$), suggesting inadequacy of assumptions employed to partition ME used in maintenance and available for ADG.

With the mature Angora goat data set used for Eq. (5) (from database 2), regressing partitioned MEI_f against CFGR resulted in equations with fairly low R^2:

unscaled :

$$MEI_f = -313\,(SE = 649.7) + (201\,(SE = 50.0) \times CFGR) \quad (n = 48;\ R^2 = 0.26)$$

scaled by BW$^{0.75}$:

$$MEI_f = 2.75\,(SE = 49.7) + (175\,(SE = 50.7) \times CFGR) \quad (n = 48;\ R^2 = 0.21)$$

Neither intercepts nor slopes differed among scaling factors, with relative high SE for both intercepts and slopes. Estimates of ME_f were somewhat greater than noted previously with the multiple regression method. With the high SE of intercepts and because with the multiple regression approach TG accounted for nearly twice the variation attributable to CFGR, use of this factorial approach and its assumptions would not seem preferable to multiple regression.

3.1.4. Summary of ME requirement expressions

Equations from the factorial approach with intercepts different from 0 and/or relatively large SE of intercepts and coefficients suggest that the assumptions employed might not have been the most appropriate for Angora goats, and that ME requirements could be more appropriately estimated with regression models also predicting ME_m and/or ME_{tg}. In regards to the numerical difference in ME_m estimates between simple and multiple linear regressions, database 2 used for multiple regression was also subjected to simple

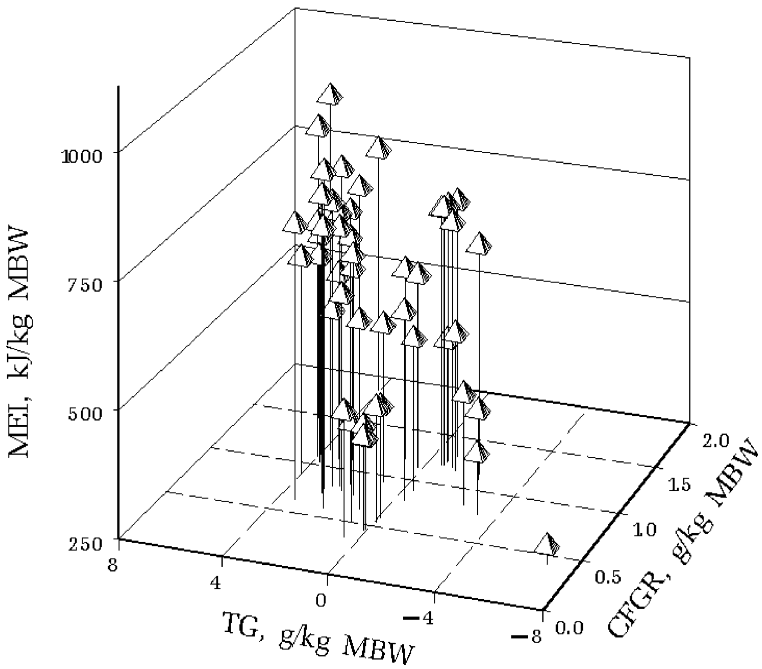

Fig. 2. Scatter plot for the regression of MEI (kJ/kg$^{0.75}$) against TG (g/kg BW$^{0.75}$) and clean fiber growth rate (g/kg BW$^{0.75}$) for mature Angora goats of database 2 after removing one observation with a residual greater than two times the R.S.D. Pyramids are observed values ($n = 48$). MBW = kg BW$^{0.75}$.

linear regression, resulting in the equation: MEI = 560 (SE = 23.1) + (39.6 (SE = 6.62) × ADG) (n = 49; $R^2 = 0.43$). Intercepts and slopes of equations were similar between databases 1 and 2 ($P > 0.25$ and 0.57, respectively), indicating that the intercept difference between simple and multiple regressions was not due to the nature of databases.

As expected, ME_g was intermediate to ME_{tg} and ME_f. By definition, differences in intercepts between simple linear and multiple regression approaches were expected. That is, ME_m for multiple regression is MEI when both TG and CFGR are 0. Conversely, the intercept for simple regression is MEI with 0 ADG, which was presumably accompanied by negative TG and positive CFGR because of the priority given to fiber growth over TG in animals selected for fiber production (ARC, 1980; Graham and Searle, 1982). Hence, even though the intercepts did not statistically differ, each should be used with the accompanying regression coefficient(s) rather than employing one average ME_m for both approaches.

As noted above, in fiber-producing ruminants there can be preferential partitioning of nutrients to fiber growth rather than TG in some circumstances (Graham and Searle, 1982). Similarly, Kellaway (1973) reported that wool production by weaned sheep was affected by plane of nutrition to a lesser extent than ADG. With low nutritional planes, Angora goats can still produce mohair without BW gain or with BW loss, although fiber production is less than with higher nutritional planes (Cronjé, 2000). Thus, effects of nutrient intake on mohair fiber growth and TG may vary with nutritional plane (ARC, 1980). Hence, in the multiple regression of MEI against TG and CFGR, the interaction of TG and CFGR was tested. The significant ($P = 0.03$) negative interaction may reflect that with low MEI, mohair fiber growth occurs at the expense of TG, in accordance with the difference in ME_m between simple linear and multiple regression approaches.

3.2. MP_m and MP_g

3.2.1. MP requirements for maintenance and whole BW gain—simple linear regression

Using the development data set from database 3, the regression of MPI (g/kg$^{0.75}$) against ADG (g/kg$^{0.75}$)

yielded the following linear equation:

$$\mathrm{MPI} = 4.52\,(\mathrm{SE} = 0.349) + (0.336\,(\mathrm{SE} = 0.0568) \times \mathrm{ADG}) \quad (n = 73;\ R^2 = 0.33) \qquad (6)$$

Five treatment means with residuals greater than 1.5 R.S.D. were removed, which appreciably decreased RMSE and increased the R^2:

$$\mathrm{MPI} = 4.30\,(\mathrm{SE} = 0.286) + (0.318\,(\mathrm{SE} = 0.0471) \times \mathrm{ADG}) \quad (n = 68;\ R^2 = 0.41) \qquad (7)$$

The five observations excluded had relatively high MPI and dietary CP concentrations. Regression lines for Eqs. (6) and (7) are presented in Fig. 3. There was no apparent pattern in residuals as ADG increased. To evaluate Eq. (7), predicted MPI ($\mathrm{MPI_{pred}}$) was calculated for the evaluation data set, and observed MPI was regressed against $\mathrm{MPI_{pred}}$. The resulting equation was: $\mathrm{MPI} = -0.18\,(\mathrm{SE} = 1.296) + (1.015\,(\mathrm{SE} = 0.2161) \times \mathrm{ADG})$ ($n = 51$; $R^2 = 0.31$). The intercept and slope of the regression did not differ from 0 ($P = 0.89$) and 1 ($P = 0.95$), respectively; therefore, the intercept and slope of Eq. (7) were considered appropriate estimates of $\mathrm{MP_m}$ and $\mathrm{MP_g}$, respectively (4.30 g/kg $\mathrm{BW^{0.75}}$ and 0.318 g/g ADG, respectively).

3.2.2. MP requirements for maintenance, tissue gain and fiber growth—multiple regression

The regression of MPI against TG and CFGR using database 4 produced the following initial

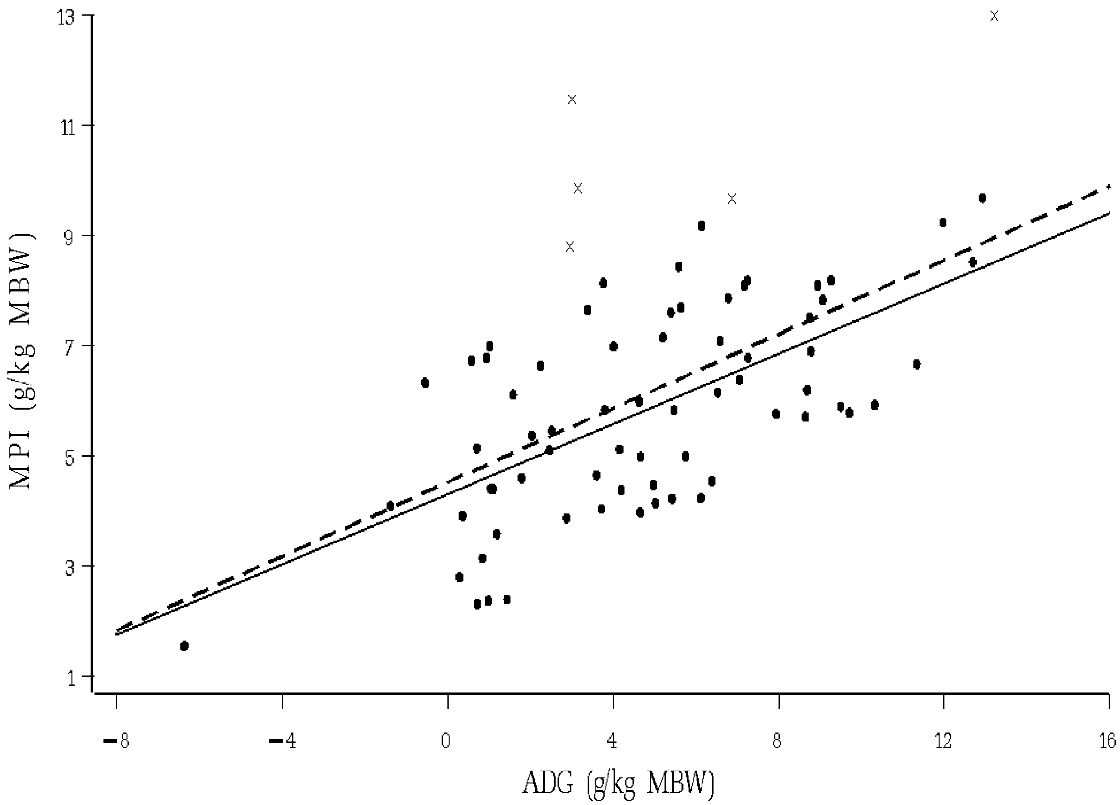

Fig. 3. Relationship between MPI (g/kg $\mathrm{BW^{0.75}}$) and ADG (g/kg $\mathrm{BW^{0.75}}$) with the development data set for growing and mature Angora goats. Points are observed values, the dashed line (---) represents the regression line of all observations and the solid line (—) is for the regression after removal of observations with high residuals (×: observations removed) and describes the equation: $\mathrm{MPI} = 4.30\,(\mathrm{SE} = 0.286) + (0.318\,(\mathrm{SE} = 0.0471) \times \mathrm{ADG})$ ($n = 68$; $R^2 = 0.41$). MBW = kg $\mathrm{BW^{0.75}}$.

equation:

$$\begin{aligned}\mathrm{MPI} = {} & 3.63\ (\mathrm{SE} = 0.475) \\ & + (0.292\ (\mathrm{SE} = 0.0538) \times \mathrm{TG}) \\ & + (1.49\ (\mathrm{SE} = 0.430) \times \mathrm{CFGR}) \\ & (n = 88;\ R^2 = 0.41) \qquad (8)\end{aligned}$$

Five observations with residuals greater than 1.5 R.S.D. were removed, resulting in this final equation:

$$\begin{aligned}\mathrm{MPI} = {} & 3.35\ (\mathrm{SE} = 0.440) \\ & + (0.281\ (\mathrm{SE} = 0.0486) \times \mathrm{TG}) \\ & + (1.65\ (\mathrm{SE} = 0.394) \times \mathrm{CFGR}) \\ & (n = 83;\ R^2 = 0.46) \qquad (9)\end{aligned}$$

The scatter plot of MPI against TG and CFGR is presented in Fig. 4. As expected, $\mathrm{MP_m}$ estimated from multiple regression (3.35 g/kg $\mathrm{BW}^{0.75}$) was less ($P = 0.03$) than that from simple linear regression (Eq. (7); 4.30 g/kg $\mathrm{BW}^{0.75}$). $\mathrm{MP_{tg}}$ and $\mathrm{MP_f}$ estimates were 0.281 g/kg $\mathrm{BW}^{0.75}$ and 1.65 g/g of clean fiber, respectively.

3.2.3. MP requirements for whole BW gain and fiber growth—factorial approach

Regressions of $\mathrm{MPI_g}$ against ADG with different scaling methods yielded the following equations:

unscaled :

$$\begin{aligned}\mathrm{MPI_g} = {} & 22.1\ (\mathrm{SE} = 3.02) \\ & + (0.250\ (\mathrm{SE} = 0.045) \times \mathrm{ADG}) \\ & (n = 124;\ R^2 = 0.20)\end{aligned}$$

scaled by $\mathrm{BW}^{0.75}$:

$$\begin{aligned}\mathrm{MPI_h} = {} & 1.87\ (\mathrm{SE} = 0.235) \\ & + (0.248\ (\mathrm{SE} = 0.0382) \times \mathrm{ADG}) \\ & (n = 124;\ R^2 = 0.26)\end{aligned}$$

$\mathrm{MP_g}$ was similar among scaling methods, but intercepts differed from 0 ($P < 0.01$). Therefore, as noted for ME requirements, assumptions to predict $\mathrm{MP_m}$ may not have been adequate, and further research seems necessary to estimate MP needs for Angora goats with a factorial approach.

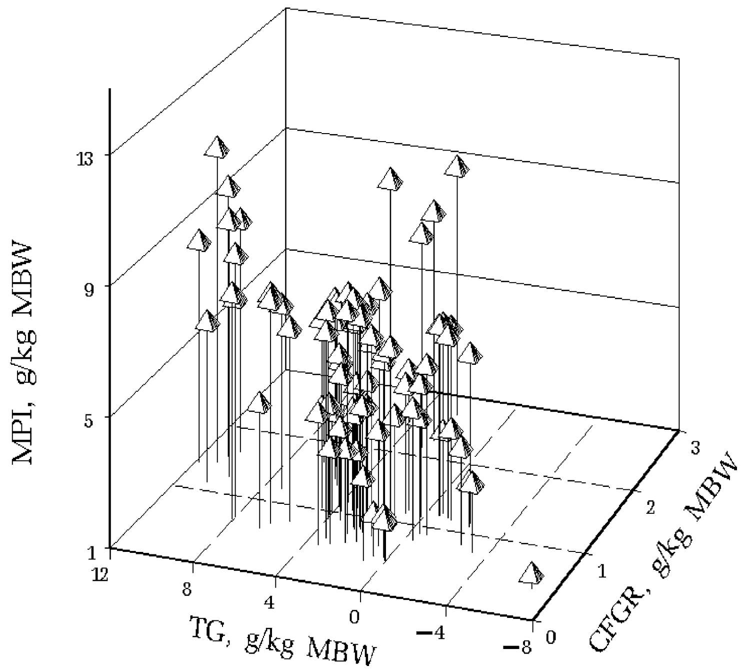

Fig. 4. Scatter plot for the regression of MPI (g/kg$^{0.75}$) against TG (g/kg$^{0.75}$) and clean fiber growth rate (g/kg$^{0.75}$) for growing and mature Angora goats of database 4. Pyramids are observed values ($n = 83$). MBW = kg $\mathrm{BW}^{0.75}$.

With database 4, regression of MPI_f against CFGR resulted in the following equations:

unscaled :

$$MPI_f = 4.78\,(SE = 5.926) + (1.83\,(SE = 0.431) \times CFGR) \quad (n = 88;\ R^2 = 0.17)$$

scaled by $BW^{0.75}$:

$$MPI_f = 1.02\,(SE = 0.415) + (1.21\,(SE = 0.358) \times CFGR) \quad (n = 88;\ R^2 = 0.12)$$

These regressions accounted for relatively little variation in MPI_f, with low R^2 and high SE of intercepts and coefficients.

3.2.4. Summary of MP requirement expressions

The factorial approach resulted in intercepts different from 0, high SE and/or low R^2. To address the cause of the difference in the intercept (MP_m estimate) between simple and multiple regression approaches, the database used for multiple regression was also employed with simple linear regression: $MPI = 4.43\,(SE = 0.269) + (0.339\,(SE = 0.0468) \times ADG)$ ($n = 83$; $R^2 = 0.39$). There were no differences in intercepts ($P = 0.63$) or slopes ($P = 0.64$) for simple regression of MPI on ADG between database 4 and the development data set of database 3; therefore, the nature of the databases was not responsible for the disparity in MP_m based on Eqs. (7) and (9). Rather, as noted for ME_m, MP_m was lower for the multiple regression approach because it represents MPI at which both TG and CFGR are 0, whereas with simple linear regression MP_m is MPI with 0 ADG, presumably associated with negative TG and positive CFGR.

4. Discussion

4.1. Energy and protein requirements for maintenance

4.1.1. Energy

ME_m estimates of the present study (533 kJ/kg $BW^{0.75}$ for simple regression with 0 ADG, and 473 kJ/kg $BW^{0.75}$ for multiple regression with both 0 TG and CFGR) were greater than recommendations for all goats of NRC (1981; 424 kJ/kg $BW^{0.75}$) and AFRC (1998; 438 kJ/kg $BW^{0.75}$). Luo et al. (2004c) determined an ME_m for mature indigenous and dairy goats of 462 kJ/kg $BW^{0.75}$ based on a regression of MEI against ADG with a compiled database in a companion study. Because the present study entailed a relatively large number of treatment mean observations with Angora goats, these expressions seem preferable to previous recommendations. However, it was not possible to address ME_m needs of growing Angora goats. Nonetheless, because Luo et al. (2004c) noted an ME_m for mature indigenous and dairy goats approximately 95% of that for growing indigenous goats, perhaps an ME_m for growing Angora goats slightly greater (e.g., 5%) than estimates for mature Angoras could be assumed.

In addition to findings of Luo et al. (2004c) and recommendations of NRC (1981) and AFRC (1998), ME_m has been determined in various individual experiments. For example, Brody (1945) described the relationship between heat produced from basal metabolism (HBM) and BW of Angora goats as: HBM (kJ) = 841 kJ kg $BW^{0.55}$, which expressed relative to $BW^{0.75}$ and mean BW of 28.3 kg in database 1 is HBM (kJ) = 431 kJ kg $BW^{0.75}$. By assuming an efficiency of ME use for maintenance (k_m) of 0.8 (assumed by Huston et al. (1971)), ME_m would be 539 kJ/kg $BW^{0.75}$, which does not encompass an allowance for energy expended in activity. Similarly, relatively high ME_m have been obtained by Armstrong and Blaxter (1984) (524 kJ/kg $BW^{0.75}$) by measuring fasting heat production and applying a k_m from cattle data. Also, via the carbon dioxide entry rate method, Herselman et al. (1999) estimated an ME_m of 661 kJ/kg $BW^{0.75}$ for grazing Angora goats. However, lower ME_m have been reported as well. Herselman and Smith (1991) reported an ME_m of 435 kJ/kg $BW^{0.75}$ for Angora goats using a multiple regression approach similar to that used in the present study. With a doubly labeled water technique, Toerien et al. (1999) noted an ME_m of 388 kJ/kg $BW^{0.75}$ for pen-fed Angora bucks and wethers. Differences in ME_m among such studies may be attributable to specific experimental conditions, methods of determination and genetic differences among Angora goats (Olthoff and Dickerson, 1989).

4.1.2. Protein

MP_m estimates of 4.30 and 3.35 g/kg $BW^{0.75}$ for simple and multiple regressions, respectively, with the former pertinent to MEI with 0 ADG and the latter with both 0 TG and CFG, are greater than proposed for all goats by AFRC (1998; 2.32 g/kg $BW^{0.75}$) based on a basal endogenous and dermal protein losses of 2.19 and 0.125 g/kg $BW^{0.75}$, respectively. Employing assumptions used in the factorial approach of the present study (i.e., EUCP, MFCP and SCP) and mean BW (27.9 kg) and DM intake (848 g per day) in database 3, NP_m was 3.02 g/kg $BW^{0.75}$. k_{pm} proposed by NRC (2001; 0.67) and AFRC (1993; 1.00) yielded MP_m of 4.51 and 3.02 g/kg $BW^{0.75}$, respectively. However, as noted before, k_{pm} of NRC (2001) resulted in too little available MPI for support of TG and CFGR. A number of factors may have been responsible for this finding. For instance, k_{pm} of 0.67 of NRC (2001) is applied to MFCP loss that is corrected for bacterial cell debris based on a number of assumptions, which would partially compensate for the lower efficiency compared with 1.00 of AFRC (1993, 1998). Also, the EUN estimate employed in the present study was determined from regression of urinary N against digestible N intake rather than total N intake, with the estimate of EUN greater for the former versus latter method (0.165 g N/kg $BW^{0.75}$ versus 0.092 g N/kg $BW^{0.75}$; Luo et al., 2004a). Furthermore, AFRC (1993) rationalized that k_{pm} is high relative to efficiencies for other tissues in part since replacement of maintenance tissues is obligatory, with available amino acids from both absorption and turnover of other tissues.

4.2. Energy and protein requirements for whole BW and tissue gain

4.2.1. Energy

The ME_g requirement determined by Luo et al. (2004c) for mature indigenous and dairy goats (28.5 kJ/g ADG) is appreciably lower than noted in this experiment for ADG (43.2 kJ/g) and TG (37.2 kJ/g). ME_g and ME_{tg} estimates were in the range of values proposed for sheep (48.1 kJ/g ADG; NRC, 1985), all goats (30.3 kJ/g ADG; NRC, 1981) and South African Angora goats (31.9 kJ/g TG; Herselman and Smith, 1991). Also, with comparative slaughter and regression analysis, Early et al. (2001) reported an ME_g of 42.1 kJ/g for Omani sheep. However, higher ME_g values were reported for five sheep breeds by Ferrell et al. (1979; 52.4 kJ/g) and Dorset wethers by MAFF (1984; 65 kJ/g). Based on a prediction equation of AFRC (1998) (TG energy concentration (kJ/g) $= 4.972 + [0.3274 \times \mathrm{BW\ (kg)}]$), for the mean BW of 32.4 kg in database 2, the energy concentration in TG was 15.6 kJ/g. This resulted in an efficiency of ME use for TG (k_{tg}) of 0.42, which is somewhat lower than 0.59 reported by AFRC (1998).

4.2.2. Protein

AFRC (1998) proposed an efficiency of MPI use for ADG of 0.24 g/g for all breeds of goats, which is less than MP_{tg} of 0.281 g/g and MP_g of 0.318 g/g in the present study. However, a much greater MP_g of 0.489 g/g was proposed for sheep by AFRC (1993). Based on the MP_{tg} estimate of the present study, with a protein concentration in TG of 14.7% (AFRC, 1998), efficiency of MP use for protein accretion in TG was 0.52, similar to 0.59 proposed for sheep (AFRC, 1993).

4.3. Energy and protein requirements for fiber growth

4.3.1. Energy

The estimate of ME_f (157 kJ/g of clean fiber) for mature Angora goats is slightly greater than 137 kJ/g determined by Herselman and Smith (1991) with a similar multiple regression approach. A much lower ME_f (45.8 kJ/g clean fiber) was recommended by NRC (1981), based on an assumed efficiency of ME use for fiber growth of 0.52 (rather than 0.33 as described in the text). However, if an efficiency of ME use for fiber growth of 0.18 is employed (SCARM, 1994), ME_f would be 139 kJ/g.

Energy retention in sheep fleece proposed by ARC (1980) was 23.7 kJ/g, in line with heat of combustion of wool protein (clean fiber) and wax of 23.47 and 40.76 kJ/g, respectively (Paladines et al., 1964). If an energy concentration in clean fiber of 23.7 kJ/g is assumed, then based on ME_f determined in the present study, efficiency of ME use for fiber growth was 0.15. Similarly, Graham and Searle (1982) reported an efficiency of ME use for wool growth (clean fiber) of 0.16–0.19 for Corriedale and Dorset Horn wether lambs. In grazing Merino sheep not pregnant or lactating, assuming an energy concentration in clean wool of 23.7 kJ/g, efficiency of ME use for clean wool growth was approximately 0.17 (Langlands and Bowles, 1974). Huston et al. (1971) also presumed that the efficiency of ME use for fiber growth of Angora goats was less than 0.20. However, AFRC (1993) suggest that if net energy retention in fiber is significant, the same efficiency of ME use for BW gain could be assumed (efficiency $= 0.006+0.0423\times$ME (MJ/kg)), which would be greater than values noted above.

4.3.2. Protein

The MP_f of 1.65 g/g of clean fiber is appreciably less than 3.85 g/g recommended by AFRC (1993) for Angora goats, based on an efficiency of utilization of MP for fiber synthesis (k_{pf}) of 0.26. Although, MP_f calculated from the digestible CP requirement listed by NRC (1981; 1.1 g/g clean fiber) and the requirement for protein digested in the small intestine of INRA (1989; 0.91 g/g clean fiber) are slightly less than MP_f of the present study. Assuming a clean fleece protein concentration of 80% (AFRC, 1993), k_{pf} in the present study was 0.48. Though k_{pf} has not been directly determined in Angora goats, findings of Hogan et al. (1979) and Reis (1979) suggested that k_{pf} in sheep is low, such as 0.26 proposed by AFRC (1993). Nonetheless, k_{pf} of the present study is similar to the k_{pf} for sheep of 0.50 proposed by NRC (1985). Likewise, SCARM (1994) suggested that k_{pf} might be in the order of 0.4–0.5, and that an even higher k_{pf} value of 0.60 could be used in factorial approaches to determine total protein requirements. The considerable variability in MP_f and k_{pf} estimates may relate to methods of determination. For example, the MP_f estimate of the present study necessitates use of an MP_{tg} of 0.281 g/g and MP_m of 3.35 g/kg $BW^{0.75}$, with the MP_m perhaps encompassing a portion of the amino acid cost of maintaining fiber-producing follicles.

5. Summary

Based on databases of treatment mean observations from the literature and regression analyses, the ME and MP requirements for maintenance, whole BW gain, tissue gain and fiber growth of Angora goats were determined. The ME requirement for maintenance of mature Angora goats from simple and multiple regression analyses (at 0 ADG and 0 TG and CFGR, respectively) were 533 and 473 kJ/kg $BW^{0.75}$, respectively; ME requirements for whole BW gain, TG and CFGR were 43.2, 37.2 and 157 kJ/g of ADG, TG and CFGR, respectively. The MP requirement for maintenance of growing and mature Angora goats from simple and multiple regression analyses (at 0 ADG and 0 TG and CFGR, respectively) was 4.30 and 3.35 g/kg $BW^{0.75}$, respectively, and MP requirements for whole BW gain, TG and CFGR were 0.318, 0.281 and 1.65 g/g of ADG, TG and CFGR, respectively.

Acknowledgements

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Appendix A

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