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Metabolizable protein requirements for maintenance and gain of growing goats

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Abstract

A database of 349 treatment mean observations, representing 3404 goats from 73 publications between 1973 and 2003, was used to determine metabolizable protein (MP) requirements for maintenance (MP_m) and growth (MP_g) of goats. Published CP degradation properties of feedstuffs and proportions of dietary ingredients were used to estimate MP intake (MPI, g/day), which was regressed against ADG, with both variables scaled by $BW^{0.75}$. Goats were classified as meat (≥50% Boer; 60 observations), dairy (selected for milk production; 129 observations) and indigenous (160 observations) biotypes. Because of differences ($P < 0.01$) among biotypes in slopes, separate regressions were initially performed—meat: MPI = 2.55(S.E. = 0.360) + (0.441(S.E. = 0.0276) × ADG) ($n = 58$; $R^2 = 0.82$); dairy: MPI = 2.83(S.E. = 0.344) + (0.299(S.E. = 0.0238) × ADG) ($n = 123$; $R^2 = 0.57$); and indigenous: MPI = 3.23(S.E. = 0.212) + (0.281(S.E. = 0.0304) × ADG) ($n = 152$; $R^2 = 0.36$). Intercepts did not differ among biotypes ($P = 0.37$), but the slope for meat goats differed ($P < 0.01$) from those for dairy and indigenous goats; therefore, data sets for dairy and indigenous goats were pooled and split into development ($n = 150$) and evaluation ($n = 125$) subsets. Using the equation derived from the development data subset for dairy and indigenous goats (i.e., MPI = 3.14(S.E. = 0.189) + (0.285(S.E. = 0.0168) × ADG) ($n = 144$; $R^2 = 0.67$)), MPI for the evaluation subset was predicted; regressing observed against predicted MPI of the evaluation data subset resulted in an intercept and slope not different from 0 and 1, respectively ($P > 0.05$). The equation from the development subset for dairy and indigenous goats was compared with the equation from the meat goat data set; there was a difference ($P < 0.01$) in slopes but not in intercepts ($P = 0.25$). Therefore, a dummy variable ($D = 1$ for meat goats and 0 otherwise) was used to develop a common intercept equation: MPI = 3.07(S.E. = 0.165) + (0.290(S.E. = 0.0150) × ADG) + (0.114(S.E. = 0.0162) × D × ADG) ($n = 202$; $R^2 = 0.75$). In conclusion, based on regression of MPI against ADG, MP_m was 3.07 g/kg $BW^{0.75}$ for all biotypes of growing goats, and MP_g was 0.404 and 0.290 g/g ADG for meat and other (dairy and indigenous) goats, respectively.

Keywords: Goat; Metabolizable protein; Maintenance; Growth

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1. Introduction

Goats are important livestock for food and economic securities, particularly in developing countries of the world. However, there has been relatively less research on requirements of goats for nutrients such as protein than for other livestock species. It is now generally accepted that to best address protein needs of ruminants, feed protein reaching the small intestine intact and microbial protein synthesized in the rumen both should be considered, along with adjustment for the extent degradation in the small intestine. In accordance, metabolizable protein (MP) systems are now in common use for various classes of livestock (INRA, 1989; Wilkerson et al., 1993; AFRC, 1998; NRC, 2001), but such systems have not yet been extensively studied with goats. AFRC (1998) proposed an MP requirement for maintenance (MP_m) of 2.19 g/kg $BW^{0.75}$ and an efficiency of MP conversion to net tissue protein gain of 59% for goats, but these estimates were based on findings with cattle and sheep. Therefore, objectives of this study were to determine MP_m and the MP requirement for gain (MP_g) for growing goats based on a database of treatment mean observations from publications of goat feeding and nutrition experiments in the literature.

2. Materials and methods

2.1. Database construction and data derivation

The database for growing goats (postweaning to 18 months of age) consisted of 349 treatment mean observations from 73 publications (Appendix), representing 3404 goats. Observations were categorized into three biotypes, meat (≥50% Boer), dairy (e.g., Saanen, Alpine, Damascus, Norwegian, Swedish Landrace and dairy crossbred) and indigenous (neither dairy nor meat, without Angora goats). The length of experiments ranged from 21 to 256 days, with an average of 87. Reports included information necessary to determine mean BW, BW gain or ADG, DM intake, ME intake, CP intake, ME and CP concentrations in the diet and dietary ingredient proportions.

A parallel database of CP degradation properties for ingredients in diets of the reports of this study was constructed (Table 1) to estimate MP intake (MPI), as described by Nsahlai et al. (2004). Briefly, CP degradation properties included soluble CP (SolP), soluble non-protein N or CP as a percentage of SolP (SolNP), insoluble protein that can be potentially degraded (slowly, relative to soluble true protein) 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 non-protein 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. Feedstuff CP degradation properties were primarily derived from NRC (2000) for SolNP; NRC (2001) and AFRC (1993) for SolP, SDP and $Rate_{SDP}$; and NRC (2001), AFRC (1993) and NRC (2000) for ADIP, with an additional small number of listings derived from other sources. To calculate ADIP, it was assumed that all CP from urea in urea-treated wheat straw was soluble in acid detergent solution. Dietary levels of the different CP fractions and $Rate_{SDP}$ were based on CP degradation properties of feedstuffs and their dietary proportions.

Level of feeding (L) was ME intake divided by the ME requirement for maintenance (ME_m). An ME_m (kJ/kg $BW^{0.75}$) 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 ($k_m = 0.503 + 0.019 \times$ 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

Table 1
Crude protein degradability properties for feedstuffs used to calculate metabolizable protein intake

Feedstuff	CP (g/g DM)	SolP (g/g CP)[a]	SDP (g/g CP)[b]	k_d (h^{-1})[c]	ADIP (g/g CP)[d]	RUDDP (g/g CP)[e]	NPCP (g/g SolP)[f]	Source[g]
Acacia macracantha leaves	0.224	0.30	0.62	0.030	0.021	0.07	0.90	Kaitho et al. (1998)
Alfalfa hay	0.183	0.25	0.65	0.290	0.180	0	0.92	AFRC (1993)
Alfalfa meal	0.192	0.28	0.66	0.067	0.125	0	1.00	NRC (2001)
Ammonium chloride	1.642	1.00	0.00		0.000	0	1.00	NRC (2000)
Apple pomace	0.063	0.25	0.61	0.035	0.315	0	1.00	Ahn et al. (2002)
Barley grain	0.138	0.25	0.70	0.350	0.050	0	0.29	AFRC (1993)
Barley hay	0.125	0.22	0.60	0.080	0.093	0.09	0.93	AFRC (1993)
Bermudagrass hay	0.100	0.37	0.52	0.080	0.088	0.03	0.25	NRC (2001)
Blood meal	0.955	0.10	0.61	0.019	0.010	0.28	0.00	NRC (2001)
Bone meal	0.132	0.18	0.48	0.072	0.000	0.34	0.00	NRC (2000)
Brewers spent grain	0.292	0.18	0.65	0.047	0.120	0.05	0.75	NRC (2001)
Casava chips (tapioca)	0.038	0.25	0.70	0.120	0.050	0	0.45	NRC (2000)
Casava peel silage	0.058	0.14	0.39	0.070	0.080	0.39	1.00	Baah et al. (1999)
Chickpea	0.266	0.12	0.82	0.071	0.010	0.05	0.23	Hadjipanayiotou (2002)
Chickpea straw	0.085	0.30	0.35	0.053	0.177	0.17	0.00	NRC (2001)
Coconut meal	0.213	0.28	0.65	0.087	0.030	0.04	0.75	NRC (2001)
Concentrate	0.137	0.58	0.30	0.063	0.022	0.09	0.45	Ahn et al. (2002)
Corn grain (ground)	0.094	0.24	0.73	0.049	0.032	0	0.73	NRC (2001)
Corn bran	0.119	0.45	0.49	0.070	0.005	0.06	0.80	AFRC (1993)
Corn gluten meal	0.650	0.04	0.91	0.023	0.046	0.01	0.75	NRC (2001)
Corn stalks	0.041	0.20	0.66	0.040	0.136	0	0.95	NRC (2000)
Cottonseed meal	0.449	0.26	0.56	0.068	0.040	0.15	0.40	NRC (2001)
Cottonseed hulls	0.041	0.30	0.35	0.053	0.177	0.17	0.00	NRC (2001)
Dried beet pulp	0.100	0.05	0.91	0.020	0.060	0	0.96	NRC (2001)
Faba bean seed	0.314	0.67	0.33	0.039	0.020	0	0.23	NRC (2001)
Flemingia macrophylla leaves	0.112	0.13	0.13	0.002	0.017	0.73	0.96	Kaitho et al. (1998)
Gliricidia leaves	0.183	0.29	0.45	0.074	0.250	0.01	1.00	Ash (1990)
Groundnut hulls	0.078	0.23	0.76	0.050	0.087	0	0.00	AFRC (1993)
Groundnut cake	0.518	0.62	0.37	0.161	0.021	0	0.23	NRC (2001)
Guatemala grass	0.087	0.23	0.68	0.020	0.089	0	0.25	Mgheni et al. (1996)
Guinea grass	0.094	0.06	0.57	0.073	0.089	0.28	0.25	Sampath et al. (1989)
Krishnachura leaves	0.145	0.18	0.60	0.028	0.200	0.02	0.92	Fleischer et al. (1998)
Leucaena leaves	0.269	0.30	0.62	0.030	0.021	0.07	0.90	Kaitho et al. (1993)
Lupin seed	0.345	0.30	0.67	0.261	0.034	0	0.68	NRC (2001)
Meat meal	0.576	0.35	0.40	0.060	0.032	0.22	0.27	NRC (2001)
Molasses	0.085	0.74	0.26	0.032	0.000	0	1.00	NRC (2001)
Mulberry (*Morus alba*) leaves	0.208	0.20	0.50	0.026	0.200	0.1	0.92	Liu et al. (2000)
Mustard oil cake	0.385	0.23	0.70	0.104	0.063	0	0.65	NRC (2001)
Napier grass	0.078	0.46	0.52	0.110	0.022	0	0.02	NRC (2000)
Oat hay	0.058	0.35	0.53	0.043	0.103	0.02	0.93	NRC (2001)
Orchardgrass hay	0.130	0.25	0.69	0.110	0.061	0	0.96	NRC (2000)
Paragrass (*Brachiaria mutica*) hay	0.092	0.09	0.70	0.054	0.110	0.1	0.95	Kalbande and Thomas (1997)
Peanut hay	0.171	0.39	0.50	0.140	0.099	0.02	0.96	NRC (2001)
Rhodesgrass hay	0.066	0.28	0.53	0.050	0.167	0.02	0.96	NRC (2001)
Rice bran	0.155	0.33	0.49	0.050	0.026	0.16	0.80	NRC (2001)
Rice straw (NaOH treated)	0.035	0.36	0.37	0.067	0.292	0	0.95	Vadiveloo (2000)

Table 1 (*Continued*)

Feedstuff	CP (g/g DM)	SolP (g/g CP)[a]	SDP (g/g CP)[b]	k_d (h^{-1})[c]	ADIP (g/g CP)[d]	RUDDP (g/g CP)[e]	NPCP (g/g SolP)[f]	Source[g]
Rice straw (urea treated)	0.035	0.11	0.66	0.034	0.138	0.09	0.95	Ibrahim et al. (1989)
Rice straw	0.053	0.41	0.42	0.023	0.168	0	0.95	Negi et al. (1988)
Sesbania grandiflora leaves	0.208	0.11	0.79	0.183	0.100	0.01	0.96	Ash (1990)
Sorghum grain	0.116	0.19	0.79	0.055	0.086	0	0.33	NRC (2001)
Sorghum-sudan hay	0.094	0.28	0.53	0.050	0.128	0.06	0.95	NRC (2001)
Soybean meal	0.499	0.05	0.93	0.037	0.020	0	0.55	Hadjipanayiotou (2002)
Soybean meal, formaldehyde treated	0.471	0.07	0.93	0.028	0.000	0	0.55	Michalet-Doreau and Nozière (1998)
Sugar cane bagasse	0.030	0.03	0.49	0.049	0.315	0.17	0.96	Ørskov et al. (1980)
Urea	2.880	1.00	0.00		0.000	0	1.00	AFRC (1993)
Vetch bran	0.256	0.56	0.44	0.167	0.010	0	0.96	NRC (2001)
Wheat bran	0.173	0.34	0.63	0.200	0.081	0	0.75	NRC (2001)
Wheat straw	0.048	0.09	0.51	0.014	0.292	0.1	0.95	NRC (2001)

[a] Soluble CP (g/g total CP).
[b] Slowly degradable protein (g/g total CP).
[c] Rate of degradation of SDP (h^{-1}).
[d] Acid detergent insoluble CP (g/g total CP).
[e] Ruminally undegraded but intexstinally digestible protein (g/g total CP). Calculated as the difference between total CP and the sum of SolP, SDP and ADIP.
[f] Non-protein CP (g/g SolP). Derived from NRC (2000).
[g] Source of degradability parameters except for NPCP.

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 data from 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):

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

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

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 $\text{Rate}_{\text{SolTP}}$:

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

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, undegraded 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 of 0.8 and in ExSDP of 1.0. Hence, effective ruminally degraded CP (ERDP) was the sum of 0.8 × ExSolNP, 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 concentrations in dietary concentrates and forages. Means of RFE were 92.6 ($n = 11$; S.D. = 4.35) and 82.0 ($n = 18$; S.E. = 2.75) of forage and concentrate ME (MJ/kg DM), respectively. These estimates were used along with ME intake and dietary concentrate and forage ME concentrations and proportions to estimate RFE (MJ/day). Using the equation proposed by AFRC (1993), microbial protein (MicP) 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, digestible microbial true protein (DMTP) was estimated as 0.6375 × MicP (AFRC, 1993). MPI was derived by adding DUDP and DMTP. A summary of important variables in the complete database for prediction of MP_m and MP_g is presented in Table 2.

2.2. Regression analyses

MPI was regressed against ADG because objectives were to determine MP requirements for maintenance and growth rather than to determine efficiencies of MP use. In addition, it is desirable for the independent variable to be the one determined with greatest accuracy. MPI and ADG were scaled by kg $BW^{0.75}$. Using PROC GLM of SAS (1990), differences among biotypes in intercepts and slopes of equations from regressions of MPI against biotype, ADG and their interaction were tested by analysis of covariance (Snedecor and Cochran, 1978). There was a difference among biotypes in slopes ($P < 0.05$), though not in intercepts ($P = 0.86$), suggesting the use of dummy variables to address the slope difference. However, because of the possibility that observations with relatively high residuals in data sets for each biotype might have contributed to the slope difference, separate regressions for each biotype were first performed.

Data for meat, dairy and indigenous goats consisted of 60, 129 and 160 treatment mean observations and represented 591, 1793 and 1019 goats, respectively. A summary of the data sets is presented in Table 3. Preceding simple linear regression, regressions of MPI against linear, quadratic and cubic effects of ADG were performed. Inclusion of quadratic and cubic ef-

Table 2
Summary of variables in the entire database ($n = 349$) for prediction of metabolizable protein requirements

Variable	Mean	S.D.	Min[a]	Max[b]
Soluble CP (g/g total CP)	0.267	0.1055	0.063	0.67
Soluble non-protein CP (g/g soluble CP)	0.63	0.2442	0.022	1
Slowly degradable protein (SDP; g/g total CP)	0.594	0.099	0.246	0.868
Rate of SDP degradation (h^{-1})	0.103	0.0651	0.024	0.35
Acid detergent insoluble CP (g/g total CP)	0.062	0.0349	0.01	0.227
DRUDP[c] (g/g total CP)	0.048	0.0568	0	0.411
Mean BW (kg)	21.8	9.34	5.5	52.2
Forage (% DM)	49	31.73	0	100
CP (% DM)	15.1	3.74	5.3	27.8
ME (MJ/kg DM)	10.2	1.75	3.6	14.4
DM intake (kg/day)	0.71	0.346	0.15	1.95
ME intake (MJ/day)	7.3	3.81	0.901	17.9
ADG (g/day)	101	77.8	−18	326
ADG (g/(kg $BW^{0.75}$ × day))	9.6	6.04	−2.4	28.1
CP intake (g/day)	110	63.4	13	312
RUDDP intake (g/day)	4.9	6.29	0	30.8
Total digestible ruminally undegraded protein intake[d] (g/day)	29	22.1	−2	102
Microbial CP (g/day)	57	33.9	6	157
Metabolizable protein intake (g/day)	66	41.8	2	203
Metabolizable protein intake (g/(kg $BW^{0.75}$ × day))	6.3	2.65	0.4	12.9

[a] Minimum.
[b] Maximum.
[c] Ruminally undegraded but intestinally digestible protein.
[d] Sum of RUDDP and ruminally undegraded soluble and insoluble true protein.

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

Variable	Meat goats[a] ($n = 60$)				Dairy goats[b] ($n = 129$)				Indigenous goats[c] ($n = 160$)			
	Mean	S.D.	Min[d]	Max[e]	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Mean BW (kg)	33.4	7.26	18.1	49	22.6	6.73	10.9	52.2	16.7	7.58	5.5	43
Forage (% DM)	50.3	17.97	12	74	40.6	35.67	0	100	55.2	31.03	0	100
CP (% DM)	16.3	2.04	10.2	23.6	15.3	3.47	8	20	14.4	4.28	5.3	27.8
ME (MJ/kg DM)	10.3	1.13	9.2	12.2	10.8	2	5.8	14.4	9.7	1.57	3.6	13.8
DM intake (kg/day)	1.1	0.39	0.47	1.95	0.77	0.265	0.34	1.41	0.52	0.23	0.15	1.45
MEI[f] (MJ/day)	10.9	3	5.7	17.9	8.5	3.83	3	17	5	2.3	0.9	14.4
CPI[g] (g/day)	178	63.4	71	312	120	55.2	34	258	76	43.4	13	255
ADG (g)	169	74.6	64	294	133	75.8	8	326	50	37	−18	222
ADG (g/kg $BW^{0.75}$)	12.1	4.7	5.94	22.9	12.8	6.61	1.3	28.1	6.19	3.8	−2.4	18.7
MPI[h] (g/day)	112	41.2	47	202	73	38.4	22	173	42	24.8	2	164
MPI (g/kg $BW^{0.75}$)	8	2.29	4.1	12.5	6.9	2.84	2.3	12.9	5.1	2.03	0.4	12.4

[a] Meat: ≥50% Boer.
[b] Dairy: Saanen, Alpine, Damascus, Norwegian, Swedish Landrace and dairy crossbreed.
[c] Indigenous: neither meat nor dairy, without Angora goats.
[d] Minimum.
[e] Maximum.
[f] ME intake.
[g] Crude protein intake.
[h] Metabolizable protein intake.

fects of ADG resulted in small differences in R^2 (i.e., 0.008, 0.018 and 0.038 for meat, dairy and indigenous goats, respectively) compared with simple linear regression. For meat and dairy goat data sets, linear, quadratic and cubic effects were not significant ($P >$ 0.36 and 0.23, respectively), but the linear effect was significant ($P < 0.01$ and 0.05, respectively) when the cubic effect was removed from the model. For indigenous goats, quadratic and cubic effects were significant ($P < 0.01$), but the linear effect was not ($P = 0.74$); however, removal of the cubic effect resulted in a significant linear effect ($P < 0.01$). Therefore, simple linear regressions were performed.

For each regression analysis, the residual (difference between actual and predicted values) for each treatment mean observation was compared with various multiples of the residual S.D. (rS.D.). Observations with residual greater than selected rS.D. were removed, and changes in 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, with retention of the maximum number of observations. Observations removed were examined for possible reasons for high residuals (Chatterjee et al., 2000). Final equations were tested for differences among biotypes in intercepts and slopes. Intercepts did not differ ($P = 0.37$) among biotypes; the slope for dairy goats was similar ($P = 0.64$) to that for indigenous goats, but the slope for meat goats differed ($P < 0.01$) from those for dairy and indigenous goats. Hence, data sets for dairy and indigenous goats were pooled, and the data for meat goats were analyzed separately. The pooled data set for dairy and indigenous goats (i.e., non-meat goats), including 275 treatment means and representing 2673 goats, was split into development and evaluation subsets by report. Data in the two subsets were made as homogeneous as possible for most important variables (e.g., MPI, ADG and mean BW) by exchange of observations from a small number of reports. Mean, minimum and maximum values for important variables are summarized in Table 4. With the development subset, linear, quadratic and cubic effects of ADG on MPI were checked to justify the use of simple linear regression as described previously. The modified equation from the development subset was used to predict MPI in the evaluation subset. Observed MPI was regressed against predictions to determine whether the intercept and slope differed from 0 to 1, respectively.

A comparison of prediction equations for meat and non-meat goats revealed similar intercepts ($P = 0.25$)

Table 4
Summary of development and evaluation subsets of pooled data set of dairy and indigenous goats for prediction of metabolizable protein requirements of growing goats

Variable	Development					Evaluation				
	n	Mean	S.D.	Min[a]	Max[b]	*n*	Mean	S.D.	Min	Max
Mean BW (kg)	150	19.3	8.33	6.4	52.2	125	18.6	6.68	5.5	35.1
DM intake (kg/day)	150	0.61	0.259	0.19	1.35	125	0.61	0.239	0.15	1.37
CP (% DM)	150	14.6	3.82	5.3	23.7	125	14.7	4.02	6.9	23.6
Forage (% DM)	150	46.8	35.84	0	100	125	52.6	31.9	0	100
CP intake (g/day)	150	91	47.9	13	236	125	90	49.8	26	258
ADG (g/day)	150	86	76.8	−18	326	125	83	62.8	0	294
ADG (g/(kg $BW^{0.75}$ × day))	150	9	6.92	−2.4	28.1	125	9	5.4	0	25
MP[c] intake (g/day)	150	54	31.7	2	147	125	52	29.3	13	173
MP intake (g/(kg $BW^{0.75}$ × day))	150	5.7	2.48	0.4	12.1	125	5.7	2.21	2.3	12.2
ME (MJ/kg DM)	150	10.2	1.95	3.6	14.4	125	10.1	1.7	5.8	12.7
ME intake (MJ/day)	150	6.5	3.6	0.9	16.7	125	6.2	2.93	1.7	17

[a] Minimum.
[b] Maximum.
[c] Metabolizable protein.

and a difference in slopes ($P < 0.01$); therefore, a dummy variable, D ($D = 0$ for non-meat goats, $D = 1$ for meat goats) was used to address the slope difference. The GLM model included ADG and the interaction of D and ADG. The final equation consisted of a common intercept for the three biotypes, a common slope for dairy and indigenous goats and a slope correction or adjustment term for meat goats. The intercept of the equation was considered the MP_m and the slope MP_g.

3. Results

3.1. Initial regressions

3.1.1. Meat goats

The equation for the regression of MPI (g/kg$^{0.75}$) against ADG (g/kg$^{0.75}$) was

$$MPI = 2.82(S.E. = 0.401) + (0.428(S.E. = 0.0310) \times ADG) \quad (n = 60;\ R^2 = 0.77;\ RMSE = 1.118) \qquad (1)$$

Although the R^2 of Eq. (1) was fairly high, removal of two observations with residuals greater than 2.0 × rS.D. yielded a slightly greater R^2:

$$MPI = 2.55(S.E. = 0.360) + (0.441(S.E. = 0.0276) \times ADG) \quad (n = 58;\ R^2 = 0.82;\ RMSE = 0.989) \qquad (2)$$

Regression lines for Eqs. (1) and (2) are presented in Fig. 1. The two excluded treatment mean observations were from the same study (Soto-Navarro et al., 2004) with Boer × Spanish wethers. Although reasons for high residuals are not apparent, these observations entailed use of diets containing corn gluten and fish meals that are relatively high in ruminally undegraded protein and ADG was low compared with others in the same study. Based on Eq. (2), preliminary estimates of MP_m and MP_g were 2.55 g/kg $BW^{0.75}$ and 0.441 g/g ADG, respectively.

3.1.2. Dairy goats

The equation for the regression of MPI (g/kg$^{0.75}$) against ADG (g/kg$^{0.75}$) was

$$MPI = 3.12(S.E. = 0.397) + (0.295(S.E. = 0.0276) \times ADG) \quad (n = 129;\ R^2 = 0.47;\ RMSE = 2.068) \qquad (3)$$

To improve fit of the model, six observations with residuals greater than 2.0 rS.D. were removed, and the resultant equation was

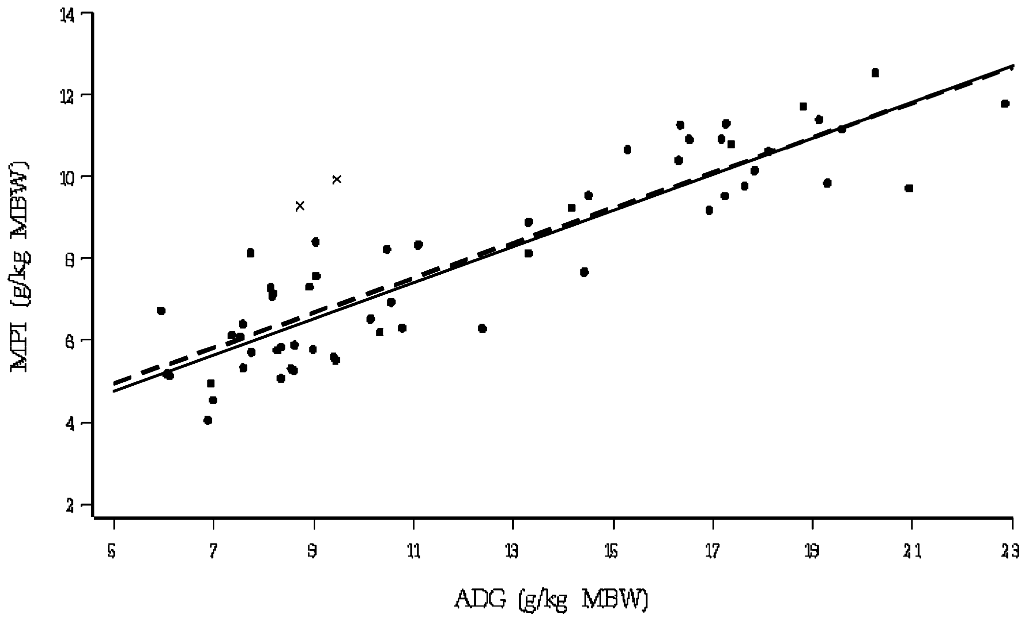

Fig. 1. Relationship between MP intake (MPI, g/kg$^{0.75}$) and ADG (g/kg$^{0.75}$) of growing meat goats. Points are observed values, the dashed line (- - -) represents the regression line for all observations in the data set and the solid line (—) is for the regression after removal of observations with high residuals (x: observations removed) and describes the equation: MPI = 2.55(S.E. = 0.360) + (0.441(S.E. = 0.0276) × ADG) (n = 58; R^2 = 0.82). MBW = kg BW$^{0.75}$.

$$\mathrm{MPI} = 2.83(\mathrm{S.E.} = 0.344) + (0.299(\mathrm{S.E.} = 0.0238) \times \mathrm{ADG}) \quad (n = 123;\ R^2 = 0.57;\ \mathrm{RMSE} = 1.778) \tag{4}$$

Regression lines for Eqs. (3) and (4) are presented in Fig. 2. The six excluded observations were above the regression line with relatively high MPI (approximately 154 g/day) and intermediate ADG (approximately 161 g/day). There were no apparent unique characteristics of these observations with respect to other variables, such as mean BW, dietary CP concentrations of CP or forage, ME intake, genotype, gender, etc. Preliminary estimates of MP_m and MP_g for growing dairy goats from Eq. (4) were 2.83 g/kg BW$^{0.75}$ and 0.299 g/g ADG, respectively.

3.1.3. Indigenous goats

The equation for the regression of MPI (g/kg$^{0.75}$) against ADG (g/kg$^{0.75}$) was

$$\mathrm{MPI} = 3.19(\mathrm{S.E.} = 0.253) + (0.306(\mathrm{S.E.} = 0.0349) \times \mathrm{ADG}) \quad (n = 160;\ R^2 = 0.33;\ \mathrm{RMSE} = 1.672) \tag{5}$$

To improve the fit of model, eight observations with residuals greater than 2.0 rS.D. were removed, yielding the following equation:

$$\mathrm{MPI} = 3.23(\mathrm{S.E.} = 0.212) + (0.281(\mathrm{S.E.} = 0.0304) \times \mathrm{ADG}) \quad (n = 152;\ R^2 = 0.36;\ \mathrm{RMSE} = 1.356) \tag{6}$$

Excluded observations did not seem to have commonalities in variables such as mean BW, breed, gender, dietary CP, ME or forage concentrations, ADG or MPI. Although Eq. (6) accounted for only 36% of variation, further deletion of observations with residuals greater than 1.5 × rS.D. resulted in a moderate increase in R^2 (i.e., 0.44) but did not appreciably change the intercept (i.e., 3.22) or slope (i.e., 0.278) and markedly decreased the number of observations in the data set (i.e., 13% change). Therefore, Eq. (6) was considered most appropriate. Regression lines for Eqs. (5) and (6) are presented in Fig. 3. Based on Eq. (6), preliminary estimates of MP_m and MP_g for growing indigenous goats were 3.23 g/kg BW$^{0.75}$ and 0.281 g/g ADG, respectively.

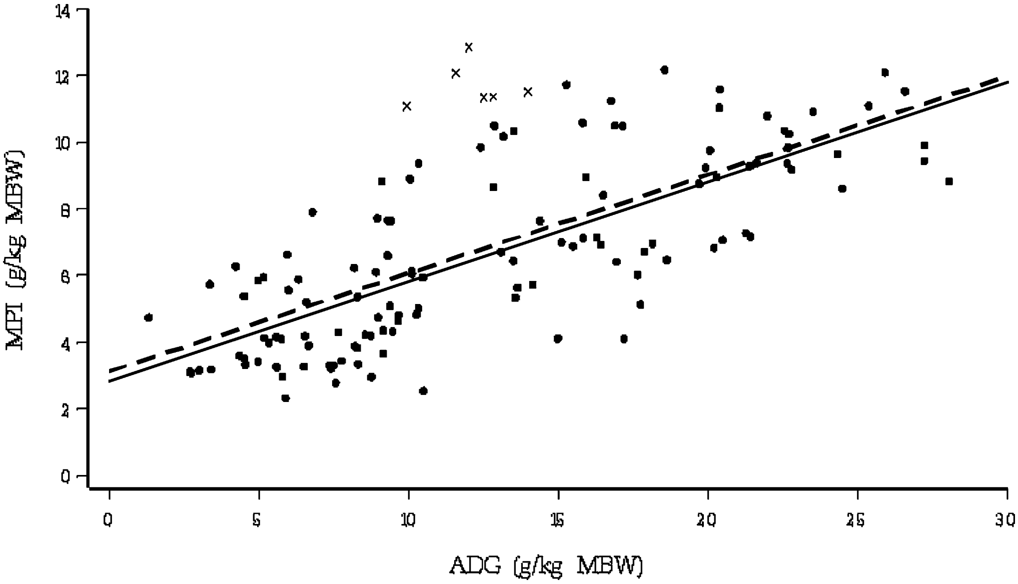

Fig. 2. Relationship between MP intake (MPI, g/kg$^{0.75}$) and ADG (g/kg$^{0.75}$) of growing dairy goats. Points are observed values, the dashed line (- - -) represents the regression line for all observations in the data set and the solid line (—) is for the regression after removal of observations with high residuals (*x*: observations removed) and describes the equation: MPI = 2.83(S.E. = 0.344) + (0.299(S.E. = 0.0238) × ADG) ($n = 123$; $R^2 = 0.57$). MBW = kg BW$^{0.75}$.

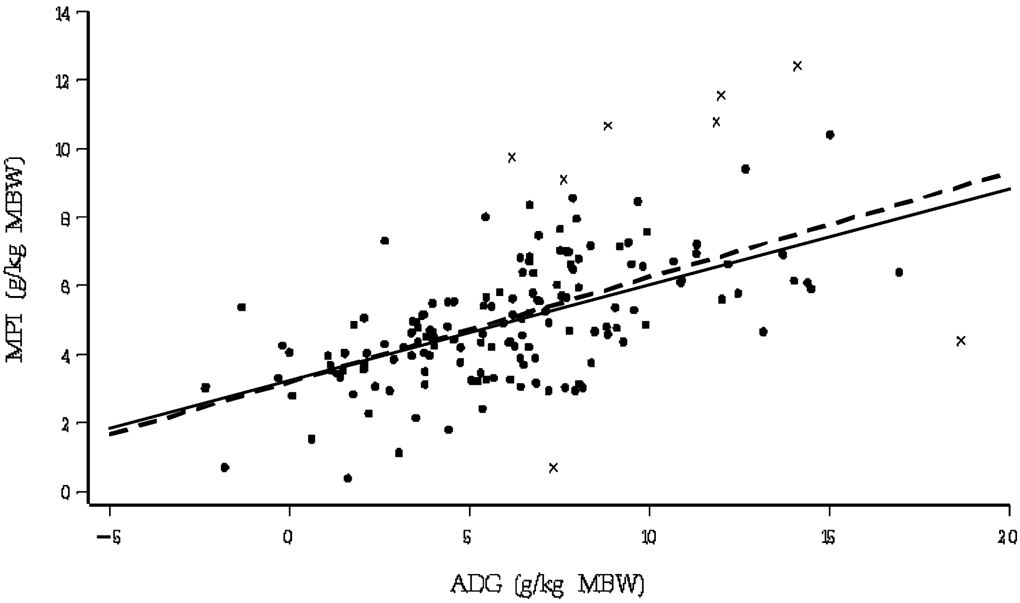

Fig. 3. Relationship between MP intake (MPI, g/kg$^{0.75}$) and ADG (g/kg$^{0.75}$) of growing indigenous goats. Points are observed values, the dashed line (- - -) represents the regression line for all observations in the data set and the solid line (—) is for the regression after removal of observations with high residuals (*x*: observations removed) and describes the equation: MPI = 3.23(S.E. = 0.212) + (0.281(S.E. = 0.0304) × ADG) ($n = 152$; $R^2 = 0.36$). MBW = kg BW$^{0.75}$.

3.2. Comparison of equations

Because of the removal of a total of 16 observations, data sets resulting in Eqs. (2), (4) and (6) were combined and differences among biotypes in intercepts and slopes were tested. Slopes differed ($P < 0.01$) and intercepts were similar ($P = 0.37$). A paired comparison test indicated a similar ($P = 0.64$) slope between dairy and indigenous goats and a difference ($P < 0.01$) in slopes between meat and non-meat (dairy and indigenous) goats; therefore, meat goat data were analyzed separately and data for dairy and indigenous goats were pooled.

3.3. MP_m and MP_g for non-meat goats

The pooled data set for non-meat goats (all observations) was split into development and evaluation subsets by report or publication. With the development subset, the linear effect of ADG on MPI was significant ($P < 0.01$), whereas quadratic ($P = 0.39$) and cubic ($P = 0.31$) effects were not; hence, a simple linear regression was conducted:

$$\text{MPI} = 3.12(\text{S.E.} = 0.206) + (0.282(\text{S.E.} = 0.0181) \times \text{ADG}) \quad (n = 150;\ R^2 = 0.62;\ \text{RMSE} = 1.529) \tag{7}$$

After removing six observations with residuals greater than 2.0 rS.D., the following modified equation was obtained:

$$\text{MPI} = 3.14(\text{S.E.} = 0.189) + (0.285(\text{S.E.} = 0.0168) \times \text{ADG}) \quad (n = 144;\ R^2 = 0.67;\ \text{RMSE} = 1.396) \tag{8}$$

Regression lines for Eqs. (7) and (8) are presented in Fig. 4. Five of the six observations removed had relatively low dietary CP and forage concentrations.

Using Eq. (8), the predicted MPI (MPI_{pred}) was calculated for the evaluation subset. The regression of observed MPI against MPI_{pred} resulted in this equa-

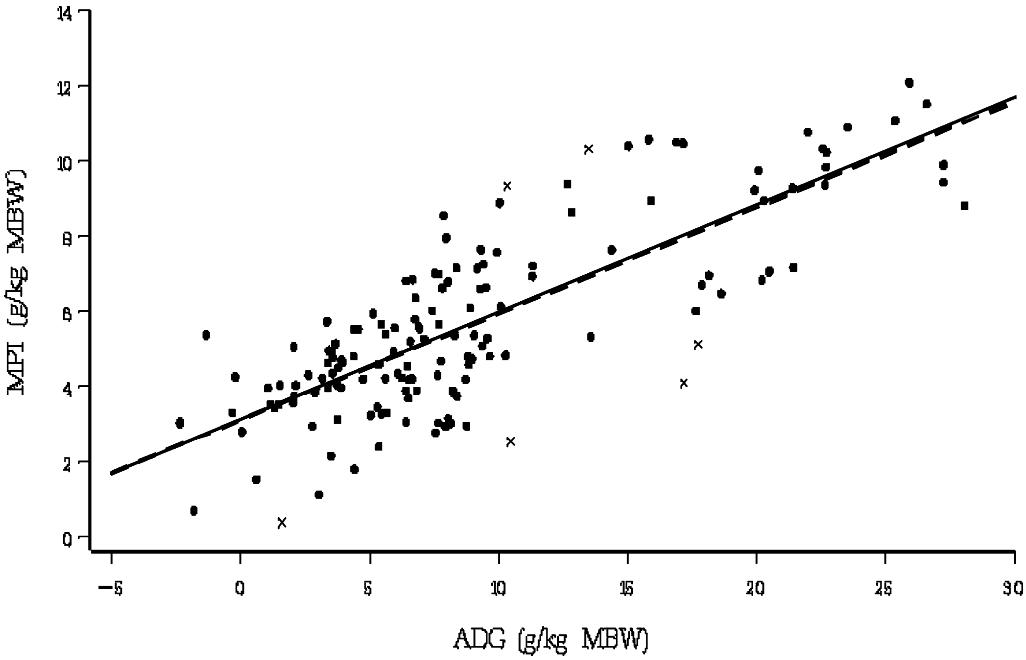

Fig. 4. Relationship between MP intake (MPI, g/kg$^{0.75}$) and ADG (g/kg$^{0.75}$) of development subset for growing dairy and indigenous goats. Points are observed values, the dashed line (- - -) represents the regression line for all observations in the data set and the solid line (—) is for the regression after removal of observations with high residuals (x: observations removed) and describes the equation: MPI = 3.14(S.E. = 0.189) + (0.285(S.E. = 0.0168) × ADG) ($n = 144$; $R^2 = 0.67$). MBW = kg BW$^{0.75}$.

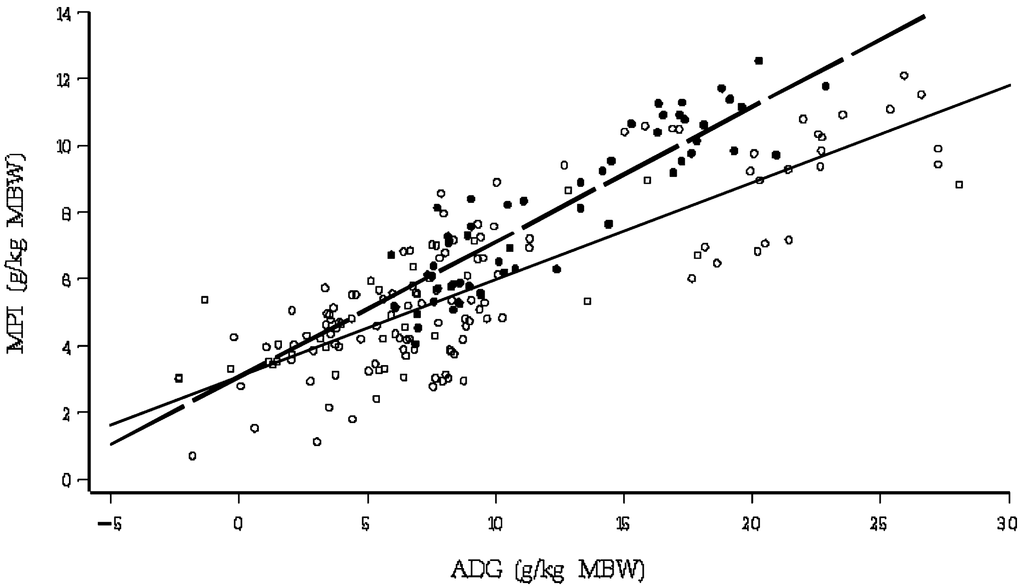

Fig. 5. Relationship between MP intake (MPI, g/kg$^{0.75}$) and ADG (g/kg$^{0.75}$) of growing goats: (●) observations for growing meat goats; (○) observations for dairy and indigenous goats. The dashed line (---) describes the regression line for growing meat goats and the solid line (—) is for growing dairy and indigenous goats. The common intercept equation is: MPI = 3.07(S.E. = 0.165) + (0.290(S.E. = 0.0150) × ADG) + (0.114(S.E. = 0.0162) × D × ADG) (n = 202; R^2 = 0.75). D = 1 for growing meat goats and 0 otherwise. MBW = kg BW$^{0.75}$.

tion: MPI = 0.022(S.E. = 0.5509) + (0.994(S.E. = 0.0933) × MPI_{pred}) (n = 125; R^2 = 0.48). The intercept and slope of the equation were not different from 0 (P = 0.97) to 1 (P = 0.96), respectively. Thus, Eq. (8) provided unbiased estimates of MP_m (3.14 g/kg BW$^{0.75}$) and MP_g (0.285 g/g ADG) for non-meat goats.

3.4. Final equation for estimations of MP_m and MP_g

Because of the removal of observations from the development data subset for non-meat goats, Eqs. (2) and (8) were tested for differences by analysis of covariance. There was a difference in slopes ($P < 0.01$) but not in intercepts ($P = 0.25$). Hence, a dummy variable D ($D = 1$ for meat goats and 0 otherwise) was used in the regression analysis. The common intercept equation from the regression of MPI against ADG was

$$\begin{aligned} \text{MPI} = {} & 3.07(\text{S.E.} = 0.165) \\ & + (0.290(\text{S.E.} = 0.0150) \times \text{ADG}) \\ & + (0.114(\text{S.E.} = 0.0162) \times D \times \text{ADG}) \\ & (n = 202;\ R^2 = 0.75;\ \text{RMSE} = 1.295) \end{aligned} \quad (9)$$

Regression lines of Eq. (9) are presented in Fig. 5. Based on Eq. (9), MP_m for all growing goats was 3.07 g/kg BW$^{0.75}$ and MP_g for meat goats and non-meat goats was 0.404 and 0.290 g/g ADG, respectively.

4. Discussion

4.1. Derivation of CP degradation properties and MPI calculation

Because few CP degradation properties have been determined with goats, and it is likely that such characteristics do not differ appreciably among ruminant species, CP degradation properties for other ruminants were used to calculate MPI. The method of estimating MPI was quite similar to that of AFRC (1993), as well as the NRC (2000) Level 1 approach. CP degradation measures used were based on in situ ruminal N disappearance as discussed by Ørskov (1980), Ørskov and MacLeod (1982) and Ørskov and Shand (1997).

4.2. MP_m

In addition to determination of MP_m by regression analysis, a factorial approach can also be used for comparison purposes. To do so, the net protein requirement for maintenance (NP_m) was assumed to be the sum of endogenous urinary CP (EUCP), metabolic fecal CP (MFCP) and scurf CP (SCP) losses. The EUCP for goats from Luo et al. (2004) of 1.031 g/kg $BW^{0.75}$ and the MFCP for goats from Moore et al. (2004) of 2.67% DM intake were used. In addition, the SCP estimate of $0.2 \times BW^{0.60}$ from NRC (1984) was assumed. Using the mean BW (21.8 kg) and DM intake (0.711 kg/day) in the database of this study, NP_m was 3.04 g/kg $BW^{0.75}$. Assuming an efficiency of MP use for maintenance (k_{pm}) of 1.00 (AFRC, 1993), the corresponding MP_m was 3.04 g/kg $BW^{0.75}$, which is very close to the estimate from regression analysis in the present study (3.07 g/kg $BW^{0.75}$). With a similar regression approach, Wilkerson et al. (1993) reported a slightly greater MP_m of growing beef steers of 3.8 g/kg $BW^{0.75}$, which was adopted as the recommendation for beef cattle of NRC (2000). However, based on seven studies in the period of 1950–1980, NRC (1981) proposed a digestible CP requirement for maintenance of goats of 2.82 g/kg $BW^{0.75}$, which based on common magnitudes of energy loss in urine equates to a slightly lower MP_m than our estimate. The MP_m requirement for goats recommended by AFRC (1998; 2.19 g/kg $BW^{0.75}$), based on data with other species, was also lower. Likewise, based on N balance of male goats in one experiment, INRA (1989) suggested an MP_m of 2.30 g/kg $BW^{0.75}$.

4.3. MP_g

With the approach used to determine MP requirements, an inherent assumption is that MP intake limited growth. It is possible that for some observations ME intake was relatively more limiting than intake of MP, which would have contributed to variability in ADG not accounted for by MP intake. However, since ME intake is a primary determinant of MP intake through its influence on microbial protein synthesis, it is most likely that the degree to which ME intake might have been more limiting than MP intake, or vice versa, was small. Nonetheless, because the MP_g requirement was determined from change in MP intake per unit change in ADG, it seems appropriate to consider this MP_g requirement a maximum rather than average and, relatedly, that supplying additional MP as a safety factor to ensure desired levels of performance is unwarranted.

Factors responsible for the greater MP_g estimate for meat goats than for dairy and indigenous goats are unclear; however, reports of a higher protein concentration in BW gain in meat goats could be involved (Mmbengwa et al., 2000). Many estimates of MP_g have been derived by separate prediction of the protein concentration in empty or live BW gain (NRC, 1985, 2000, 2001; AFRC, 1993, 1998) and an assumed constant efficiency of MP use for growth (k_{tg}), resulting in a wide range of MP_g. This method was not used in the present study because composition of gain was not reported in most publications and there is not currently available an accurate means of prediction for a wide array of goat genotypes and production systems. The MP_g of 0.24 g/g ADG for all goats of AFRC (1998) based on this approach is somewhat lower than determined in the present study (i.e., 0.290 g/g ADG for non-meat goats and 0.404 g/g ADG for meat goats). This difference may be ascribed to factors such as method of determination, the assumption of AFRC (1998) for k_{tg}, experimental conditions, body composition, growth rate, etc. For example, protein concentration in tissue gain of beef cattle decreases, and that of fat increases, as growth rate and BW increase (Byers, 1982). However, our findings by regression analysis are in line with cattle studies in which MP_g was assumed constant (INRA, 1989; Ainslie et al., 1993; Wilkerson et al., 1993). For example, Wilkerson et al. (1993), with a similar regression approach, noted an MP_g for growing beef steers of 0.305 g/g ADG. Likewise, INRA (1989) reported an MP_g value of 0.36 g/g ADG for all goats.

4.4. *Efficiency of MP use for maintenance and growth of goats*

Assumed efficiencies of MP use for maintenance (k_{pm}) vary widely among protein systems (0.75 for ARC, 1980; 0.70 for SCARM, 1994; 1.00 for AFRC, 1998; 0.67 for NRC, 2001). To compare our estimate of MP_m from regression analysis to that with a factorial approach, the k_{pm} assumed was 1.00, based on the justification of AFRC (1992) and concepts outlined by Oldham (1987) regarding amino acid requirements of non-ruminants. NRC (2001) proposed a k_{pm} value of 0.67; however, the correction of MFCP by NRC (2001) for bacterial cell debris based on several assumptions would partially compensate for the lower k_{pm}.

Net protein gain is the multiple of ADG and composition of gain, with the latter influenced by growth rate, physiological maturity, previous nutrition, gender, etc. (NRC, 1985). Protein concentration in BW gain can be calculated assuming a concentration in empty BW gain such as 16% (AFRC, 1998) and conversion to a live BW basis by dividing by 1.09 (ARC, 1980), resulting in 147 g/kg. Also, with the equation of AFRC (1998) (protein concentration in BW gain, g/kg = 157.22 − [0.694 × BW, kg]) and mean BW (33.4 and 19.3 for meat and non-meat goats, respectively), protein concentration in BW gain was 134 and 144 g/kg for meat and non-meat goats, respectively. Efficiency of MP use for protein accretion (k_{tg}) for growing meat and non-meat goats, respectively, was 0.36 and 0.51 from the first method and 0.33 and 0.50 from the second. The meat goat k_{tg} is lower than values of NRC (1985, 0.50), INRA (1989, 0.65), AFRC (1993, 1998, 0.59) and SCARM (1994, 0.70). Although it is possible that protein turnover is relatively high in meat goats, because MP_m was similar among genotypes, this difference could involve a greater protein concentration in BW gain by meat goats than predicted by these two methods.

5. Summary

Using a database of treatment mean observations from reports with growing goats, along with feedstuff CP degradation properties, MP requirements were determined by regressing MPI against ADG. The MP requirement for maintenance was 3.07 g/kg $BW^{0.75}$, and the MP requirement for BW gain of meat goats was 0.404 g/g ADG and that for dairy and indigenous goats was 0.290 g/g ADG. Because of the large number of observations on which these estimates are based, they seem useful in determining diet composition for growing goats as well as predicting performance. However, because MPI may not have in all instances been more limiting to growth than ME intake, it seems appropriate to consider the estimates as maximum requirements rather than averages and, relatedly, that supplying additional MPI as a safety factor is unwarranted.

Acknowledgements

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Appendix

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