



Metabolizable protein requirements of lactating goats

I.V. Nsahlai^{a,b}, A.L. Goetsch^{a,*}, J. Luo^{a,c}, Z.B. Johnson^d, J.E. Moore^e, T. Sahlu^a,
C.L. Ferrell^f, M.L. Galyean^g, F.N. Owens^h

^a *E (Kika) de la Garza Institute for Goat Research, Langston University, P.O. Box 730, Langston, OK, 73050, USA*

^b *Department of Animal and Poultry Science, University of Natal, P/Bag X01, Scottsville PMB 3209, South Africa*

^c *College of Animal Science and Technology, Northwest Science-Technology, University of Agriculture and Forestry, Yangling, Shaanxi, 712100, China*

^d *Department of Animal Science, University of Arkansas, Fayetteville, AR 72701, USA*

^e *Department of Animal Science, University of Florida, Gainesville, FL 32611, USA*

^f *US Meat Animal Research Center, P.O. Box 166, Clay Center, NE 68933, USA*

^g *Department of Animal Science and Food Sciences, Texas Tech University, Box 42141, Lubbock, TX 79409-2141, USA*

^h *Pioneer Hi-Bred International, Crop Genetics Research and Development, 7100 NW 62nd Street, P.O. Box 1000, Johnston, IA 50131, USA*

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Abstract

Data from 30 studies with 173 treatment mean observations of lactating goats were used to determine metabolizable protein (MP) requirements for lactation (MP_l). Milk protein yield (MkP) was calculated from milk yield and protein concentration. MP was estimated from dietary ingredient composition and a feedstuff database of CP degradability properties and ruminal fermentable energy concentration. MP_l was estimated with a factorial method by subtracting MP used for maintenance, which was the sum of scurf (0.2 g/kg BW^{0.6}), endogenous urinary (1.03 g/kg BW^{0.75}) and metabolic fecal CP losses (2.67% DM intake) divided by an efficiency of use of MP for maintenance of 1.0. Also, MP was adjusted for BW change (14.3% protein), assuming an efficiency of MP use for protein accretion of 0.59 and that mobilized tissue protein was used for lactation with the same efficiency as MP from the diet or microbial cells. The equation for the regression of MP_l (g/day) against MkP (g/day) was: MP_l = 15.2 (S.E. = 7.77) + 1.30 (S.E. = 0.090) × MkP (*n* = 163, adjusted-*R*² = 0.56); the intercept was not different from zero (*P* > 0.05). The slope of a no-intercept equation (regression line forced through the origin) was 1.45 (S.E. = 0.033). In conclusion, these results suggest a MP_l requirement for goats of 1.45 g/g of MkP or a milk protein efficiency of 0.69. Because of the approach employed, application of this MP_l requirement should not include provision of additional MP as a safety factor. With the large number of observations in this database, this requirement estimate should be of value in expressing protein needs and predicting performance of lactating goats, although future research to refine assumptions may improve accuracy.

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1. Introduction

In most livestock production systems, providing adequate dietary protein is costly because protein-rich

* Corresponding author. Tel.: +1-405-466-3836;

fax: +1-405-466-3138.

E-mail address: goetsch@luresext.edu (A.L. Goetsch).

feedstuffs are typically more expensive than ones lower in protein. Unfortunately, variable proportions of consumed protein are degraded in the rumen, primarily to ammonia. Most protein reaching the small intestine in ruminants is from undegraded feed protein and protein from synthesized microbial cells. Use of ammonia for synthesis of microbial matter depends largely on availability of energy derived from fermentation (Witt et al., 1999). Therefore, there is need to balance quantities and the temporal pattern of availabilities of energy and ammonia in the rumen. This has led to the partitioning of protein of dietary ingredients into fractions that behave differently in the ruminant digestive tract, i.e., CP soluble and degraded in the rumen, ruminally degraded insoluble protein, ruminally undegraded insoluble protein and indigestible protein (NRC, 1989, 2000; INRA, 1989; AFRC, 1993). In addition, NRC (2000) considered both nonprotein and true protein fractions of soluble CP. By applying ruminal dilution or passage rates of fluid and particulate digesta, knowledge of these fractions can be used to estimate effective ruminally degraded CP. Apart from the usefulness of such protein systems to accurately predict flow of fed natural and microbial protein from the rumen to achieve high levels and efficiencies of ruminal performance, they also can contribute to maximization of capture of ammonia in microbial cells to minimize wasteful excretion of urea in urine and avert potential negative environmental consequences.

Most systems of protein evaluation rely on empirical equations to predict microbial protein synthesis (e.g., NRC, 1989, 2000; Russell et al., 1992; AFRC, 1993). Given the codependency of microbial synthesis on availabilities of energy and nitrogenous compounds, AFRC (1993) adopted a strategy whereby synthesized microbial matter is based on limits set by either dietary characteristic. The sum of digestible but ruminally undegraded dietary protein and digestible microbial true protein is commonly referred to as metabolizable protein (MP; AFRC, 1998) or protéine digestible dans l'intestin (INRA, 1989).

NRC (1981) based protein requirements of goats for lactation on a digestible CP (DCP) system for dairy cattle (NRC, 1978) because of lack of adequate experimentation with goats available at that time. However, a system of protein evaluation based on absorbed amino acid N, such as those of AFRC (1998) or INRA (1989), should more accurately describe requirements and pre-

dict performance by lactating goats. AFRC (1998) summarized the small number of reports available at that time in which protein requirements of lactation by goats were addressed, concluding that insufficient data were available to recommend a MP requirement different from that based on data from other ruminant species (i.e., 1.47 g MP/g milk protein; AFRC, 1992). Our objective was to directly determine the MP requirement for milk protein synthesis by lactating goats with available goat data.

2. Materials and methods

The database consisted of 173 treatment mean observations from 30 publications, which are summarized in Table 1. There were 136 observations from Alpine, Damascus, Nubian and Saanen goats, and 37 from other breeds producing less milk protein (i.e., <76.1 g/day). Hence, observations were categorized as high milk-producing breeds or others. Similarly, observations were classed as early (1–10 weeks of lactation) or mid-to-late lactation.

A parallel database of CP degradability properties for dietary ingredients was constructed (Table 2). When not provided in the original report, 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

Table 1

Summary of database to determine the metabolizable protein requirement for lactation by goats

Ref ^a	Source	Forage		Breed ^b	No. of animals	Study type ^c	BW (kg)	ADG (g) ^d		Milk CP (g/day)	MP ^e (g/day)	
		Type ^f	% ^g					Min	Max		Calculated	Predicted
788	Abijaoude et al. (2000)	AH, SBP silage	30–35	1, 2	24	LS, 21	65–66	69	105	54–61	79	84
428	Aguilera et al. (1990)	Pelleted AH	35–40	7	12	P, 12	34–41	–49	79	37–53	39	64
140	Cizuk and Lindberg (1988)	Hay, straw	40	20	14	P, 35	47–54	–66	125	57–85	77	98
140	Economides (1986)	AH	32–38	5	21	C, 75	44–69	13	67	109–199	135	160
495	Eik (1991)	Grass silage	–	15	39	C, 133	34–50	–95	24	47–76	87	96
485	El-Gallad et al. (1988)	Berseem, clover hay, sweet sorghum	20–40	3	24	C, 224	30–31	–3	6	16–20	78	26
836	Fernandez et al. (1988)	CSH	39–42	1	18	C, 35	43–49	66	131	42–48	74	67
827	Fernandez et al. (1997)	CSH	38–43	1	38	C, 56, 70	42–63	–3	114	42–78	123	88
605	Goetsch et al. (2000)	CSH, AH	40–80	1	62	C, 112	36–59	16	93	43–116	127	109
739	Goetsch et al. (2001)	CSH, AH	35–80	1	47	C, 112, 84	53–61	–189	71	95–125	164	168
53	Hadjipanayiotou (1992)	BH	22–24	5	21	C, 35	65–66	–11	14	103–108	129	154
231	Hadjipanayiotou (1984)	BS (urea-treated)	14–17	5	36	C, 35	63	2	5	67	60	99
230	Hadjipanayiotou (1981)	BH	13–27	5	40	C, 70	63–64	–7	40	85–93	80	129
320	Hadjipanayiotou (1988)	BH	12–14	5	18	C, 56	62–63	11	26	82–85	95	122
293	Hadjipanayiotou (1995)	BH, BS	30	5	39	C, 52	73	–75	–52	97–99	137	144
241	Hadjipanayiotou et al. (1988)	BH, AH	30	5	32	C, 52	67–68	–27	–71	134–153	227	217
374	Hadjipanayiotou and Phoutiou (1995)	BH, BS	–	5	48	C, 42	63–68	–202	–156	55–64	74	85
296	Hadjipanayiotou et al. (1996)	BS, BH	25	5	58	C, 83	71–74	–199	47	98–112	130	154
533	Hussain et al. (1996)	Hay, silage	20–23	19	104	C, 42	44–45	26	183	24–33	12	41
298	Kawas et al. (1991)	Cunha silage	45–75	14	27	LS, 28	37	–50	120	16–22	32	28
258	Lu et al. (1990a)	AM, CSH	40–45	1	18	C, 84	49	8	24	65–75	129	105
300	Lu et al. (1990b)	CSH	33–37	1	0	C, 105	48	31	51	89–96	130	136
343	Lu (1993)	CSH	29–36	1	14	C, 119	47	6	25	73–78	162	111
842	Rapetti et al. (2001)	IRS	0–28	2	8	C, 8	47–62	29	125	74–140	147	164
96	Sahlu et al. (1993)	AM	5	1	24	C, 91	58–63	–30	2	88–108	196	137
828	Sahlu et al. (1999)	AM, AH, GH	24–38	1	28	C, 98	43–44	35	62	23–38	56	43
941	Santini et al. (1991)	AH	37–82	1	20	C, 28	60–62	7	100	122–146	146	208
94	Santini et al. (1992)	AH	37–82	1	10	C, 40	62–65	–80	–40	104–123	164	81
657	Sanz Sampelayo et al. (1998)	AH (long/pelleted)	44–49	7	10	C, 19	49–50	–67	–34	43–44	67	64
707	Schmidely et al. (2002)	Pelleted AH, SBP silage	70	1, 2	24	LS, 28	59–67	–111	172	118–159	198	205

^a Database reference number.^b 1: Alpine; 2: Saanen; 3: Nubian; 5: Damascus; 7: Granadina; 12: indigenous feral; 14: cross-bred (indigenous × dairy); 15: cross-bred (indigenous × fiber); 19: other dairy; 20: Swedish landrace.^c C: continuous feeding; LS: Latin square; P: periods with different diets or stages of lactation; length of experiments or periods is given in days.^d Min: minimum; max: maximum.^e Metabolizable protein for lactation.^f AH: alfalfa hay; SBP: sugar beet pulp; CSH: cottonseed hulls; BH: barley hay; BS: barley straw; AM: alfalfa meal; IRS: Italian rye grass silage; GH: grass hay.^g Values are percentages of DM.

Table 2
CP degradability properties of dietary ingredients for lactating goats

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	DRUDP (g/g CP) ^e	NPCP (g/g SolP) ^f	Source ^g
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)
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)
Barley straw	0.043	0.47	0.27	0.120	0.257	0	0.95	NRC (2001)
Beans	0.333	0.42	0.56	0.160	0.009	0.01	0.23	AFRC (1993)
Blood meal	0.955	0.10	0.61	0.019	0.010	0.28	0.00	NRC (2001)
Canola meal	0.393	0.18	0.81	0.044	0.064	0	0.65	NRC (2001)
Casava (tapioca)	0.038	0.25	0.70	0.120	0.050	0	0.45	NRC (2000)
Clover hay	0.178	0.39	0.50	0.140	0.067	0.05	0.96	NRC (2001)
Coconut meal	0.213	0.28	0.65	0.087	0.030	0.04	0.75	NRC (2001)
Concentrate (dairy)	0.206	0.34	0.54	0.140	0.027	0.09	0.51	AFRC (1993)
Corn grain (ground)	0.094	0.24	0.73	0.049	0.032	0	0.73	NRC (2001)
Corn silage	0.087	0.51	0.30	0.044	0.091	0.09	1.00	NRC (2001)
Cottonseed meal	0.449	0.26	0.56	0.068	0.040	0.15	0.40	NRC (2001)
Dried sugar beet pulp	0.100	0.05	0.91	0.020	0.060	0	0.96	NRC (2001)
Feather meal	0.920	0.23	0.24	0.066	0.320	0.21	0.89	NRC (2001)
Fish meal	0.685	0.23	0.72	0.014	0.010	0.04	0.00	NRC (2001)
Grape skin cake	0.067	0.27	0.62	0.110	0.110	0	0.96	NRC (2000)
Grass hay	0.133	0.37	0.52	0.081	0.090	0.03	0.02	NRC (2001)
Grass silage	0.140	0.63	0.31	0.130	0.058	0.09	1.00	AFRC (1993)
Groundnut cake	0.518	0.62	0.37	0.161	0.021	0	0.23	NRC (2001)
Meat and bone meal	0.542	0.18	0.48	0.072	0.032	0.31	0.27	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)
Oats	0.132	0.65	0.29	0.174	0.023	0.04	0.19	NRC (2001)
Palm kernel cake	0.194	0.24	0.70	0.070	0.097	0	0.75	AFRC (1993)
Rice bran	0.155	0.33	0.49	0.050	0.026	0.16	0.80	NRC (2001)
Sorghum grain	0.116	0.19	0.79	0.055	0.086	0	0.33	NRC (2001)
Soybean hulls	0.141	0.23	0.72	0.062	0.072	0	0.72	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 Noziere (1998)
Sugar beet pulp silage	0.100	0.05	0.91	0.020	0.060	0	0.96	NRC (2001)
Sunflower meal	0.284	0.42	0.53	0.292	0.049	0	1.00	NRC (2001)
Urea	2.880	1.00	0.00		0.000	0	1.00	AFRC (1993)
Urea-treated barley straw	0.070	0.70	0.20	0.080	0.098	0	0.98	AFRC (1993)
Wheat bran	0.173	0.34	0.63	0.200	0.081	0	0.75	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 intestinally digestible protein (g/g total CP). Calculated as the difference between total CP and the sum of SolP, SDP and ADIP.

^f Nonprotein CP (g/g SolP). All NPCP values were derived from NRC (2000).

^g Source of degradability parameters except for NPCP.

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), cited by AFRC (1993), 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). A ME_m (kJ/kg of $BW^{0.75}$) of $315/k_m$ was assumed based on AFRC (1998) recommendations for the net energy for maintenance requirement of 315 kJ/kg of $BW^{0.75}$ and efficiency of ME utilization for maintenance ($k_m = 0.503 + 0.019 \times ME$, MJ/kg of 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_1) was determined as a function of k_p : $k_1 = (k_p - 0.0018)/0.360$. 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):

$$\text{ExSolTP} = \text{SolTP} \times \frac{\text{Rate}_{\text{SolTP}}}{\text{Rate}_{\text{SolTP}} + k_1} \quad \text{and}$$

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

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 the

equation:

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

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 synthesis of 0.8 and in ExSDP of 1.0. Hence, effective capture ruminally degraded CP (ERDP) was the sum of $0.8 \times \text{SolNP}$, $0.8 \times \text{ExSolTP}$ and $1.0 \times \text{ExSDP}$. 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 92.6 ($n = 11$; S.D. = 4.35) and 82.0% ($n = 18$; S.E. = 1.75) of the ME concentration (MJ/kg) in forage and concentrate, 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 (MicP) was estimated for conditions with adequate ruminal availability of nitrogenous compounds as

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

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 $0.6375 \times \text{MicP}$ (AFRC, 1993). MP intake was derived by adding DUDP and DMTP.

Maintenance functions for which MP was considered used for include scurf, metabolic fecal and endogenous urinary. NRC (1984) estimated scurf CP

for beef cattle as a function of BW: scurf CP (g) = $0.2\text{BW}^{0.6}$. Luo et al. (2004a) described endogenous urinary N for goats as $0.165 \text{ g/kg BW}^{0.75}$. Similarly, Moore et al. (2004) estimated metabolic fecal CP for goats as 2.67% of DM intake. To determine MP required for maintenance, the sum of these three losses was divided by efficiencies of MP use for maintenance (k_{pm}) of 0.67 (NRC, 1989) and 1.0 (AFRC, 1993), followed by subtraction from MP intake to obtain MP available for milk protein synthesis and ADG (MP for production; MP_p). It was further assumed that tissue lost or gained contained 14.3% protein (AFRC, 1993). With positive BW change, the efficiency with which dietary MP was used for protein accretion was assumed to be 0.59 (AFRC, 1993, 1998). With negative BW change, mobilized protein was assumed to be used for lactation with the same efficiency as MP from the diet. To estimate MP_1 , MP used for tissue protein accretion was subtracted from MP_p or MP from mobilized tissue was added to MP from the diet.

Ten treatment mean observations with residuals greater than 2.5 times the S.D. from an initial regression of MP_1 against MkP were excluded. In addition to the simple linear regression, quadratic effects of MkP were tested and found nonsignificant ($P > 0.78$). Regressions were conducted by REG or GLM procedures of SAS (1990).

Considering ranges in MkP, MP_p , MP_1 , $\text{BW}^{0.75}$ and ADG and the different genotypes and stages of lactation of observations, it was felt that the database was not large enough to be split into a data subset for equation development and one for evaluation. Hence, prediction equations were evaluated with the same database. Observed values were regressed against predictions, and to evaluate existence of obvious bias, intercepts and slopes were tested for differences from 0 and 1, respectively. Also, residual (observed minus predicted) values were plotted against observations.

3. Results

3.1. $k_{pm} = 0.67$

The relationship between MP_1 with a k_{pm} of 0.67 and MkP is shown in Fig. 1. The equation for the

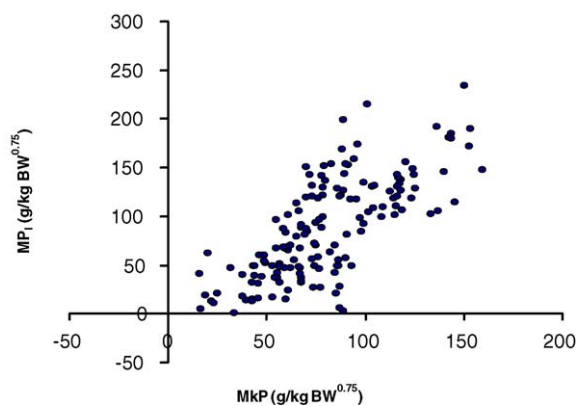


Fig. 1. Relationship between metabolizable protein (MP) for lactation (MP_1) and milk protein yield (MkP) for goats, assuming an efficiency of MP use for maintenance of 0.67. $\text{MP}_1 = -3.1$ (S.E. = 7.73) + 1.12 (S.E. = 0.089) \times MkP (adjusted- $R^2 = 0.49$; RMSE = 35.7, $n = 163$, Eq. (1)). Slope for the no-intercept equation = 1.09 (S.E. = 0.032).

regression of MP_1 against MkP was

$$\begin{aligned} \text{MP}_1 = & -3.1 \text{ (S.E. = 7.73)} + 1.12 \text{ (S.E. = 0.089)} \\ & \times \text{MkP} \quad (\text{adjusted-}R^2 = 0.49; \text{RMSE} \\ & = 35.7, n = 163) \end{aligned} \quad (1)$$

The intercept did not differ ($P > 0.05$) from zero; hence, the regression was forced to pass through the origin, resulting in a slope of 1.09 (S.E. = 0.032). This slope corresponds to an efficiency of MP_1 use for milk protein synthesis of 0.92 (S.E. = 0.015). Using the S.E. of the zero intercept equation, 100 random sample slopes were generated (based on the equation: $1.09 + (R \times \text{S.E.})$, where R is a random real number between 1 and -1), with the S.E. of their reciprocals representing the S.E. of the efficiency. In addition, reciprocals of the MP_1 requirement 1 S.E. greater and less than the mean were 0.89 and 0.95, respectively. A regression of observed values against ones predicted from the no-intercept model had an intercept of -3.1 (S.E. = 7.73) and slope of 1.03 (S.E. = 0.082), which also were not different ($P > 0.05$) from 0 and 1, respectively. Residual plots are given in Fig. 2, with that for the full equation (with intercept) in Fig. 2A and for the no-intercept equation in Fig. 2B. Categories for milk production potential and stage of lactation had nonsignificant ($P > 0.05$) effects when included as fixed effects in regressions with both k_{pm} , and interactions with the slope were nonsignificant as well.

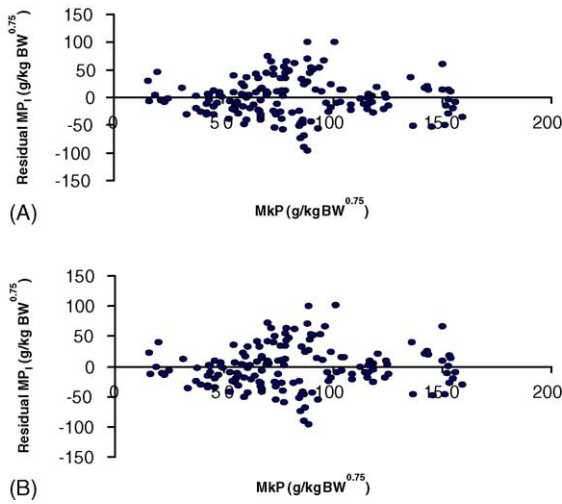


Fig. 2. Relationship between residual metabolizable protein for lactation (MP_1) and observed milk protein yield (MkP) for goats, assuming an efficiency of MP use for maintenance functions of 0.67. (A) $MP_1 = -3.1$ (S.E. = 7.73) + 1.12 (S.E. = 0.089) \times MkP (adjusted- $R^2 = 0.49$; RMSE = 35.7, $n = 163$, Eq. (1)); (B) slope for the no-intercept equation = 1.09 (S.E. = 0.032).

3.2. $k_{pm} = 1.0$

The relationship between MP_1 with a k_{pm} of 1.0 and MkP is shown in Fig. 3. The equation for the regression of MP_1 against MkP was:

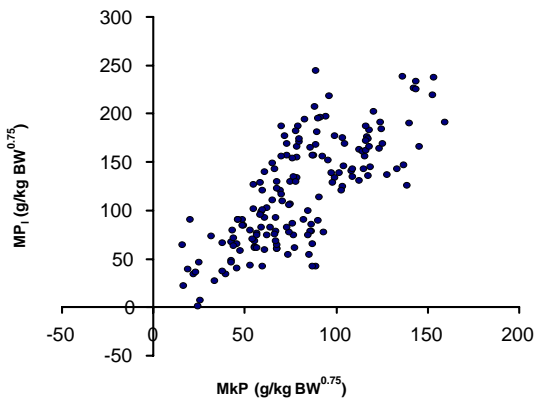


Fig. 3. Relationship between metabolizable protein for lactation (MP_1) and milk protein yield (MkP) for goats, assuming an efficiency of MP use for maintenance functions of 1.0. $MP_1 = 15.2$ (S.E. = 7.77) + 1.30 (S.E. = 0.090) \times MkP (adjusted- $R^2 = 0.56$; RMSE = 36.4, $n = 163$, Eq. (2)). Slope for the no-intercept equation = 1.45 (S.E. = 0.033).

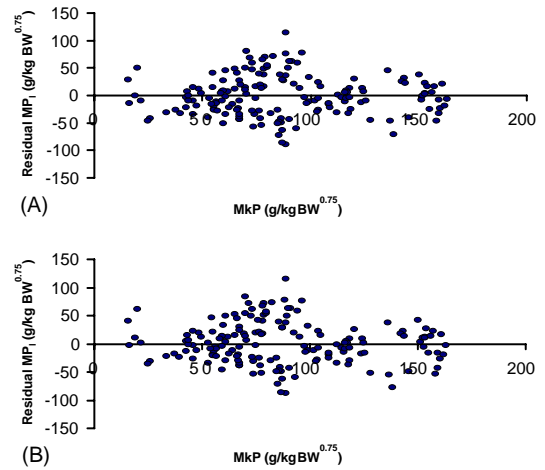


Fig. 4. Relationship between residual metabolizable protein for lactation (MP_1) and observed milk protein yield (MkP) for goats, assuming an efficiency of MP use for maintenance functions of 1.0. (A) $MP_1 = 15.2$ (S.E. = 7.77) + 1.30 (S.E. = 0.090) \times MkP (adjusted- $R^2 = 0.56$; RMSE = 36.4, $n = 164$, Eq. (2)); (B) slope for the no-intercept equation = 1.45 (S.E. = 0.033).

$$MP_1 = 15.2 \text{ (S.E. = 7.77)} + 1.30 \text{ (S.E. = 0.090)} \times \text{MkP} \quad (\text{adjusted-}R^2 = 0.56; \text{RMSE} = 36.4, n = 163) \quad (2)$$

The intercept did not differ ($P > 0.05$) from zero, and when the regression was forced to pass through the origin the slope was 1.45 (S.E. = 0.033), equivalent to a milk protein efficiency of 0.69 (S.E. = 0.009). Reciprocals of the MP_1 requirement 1 S.E. greater and less than the mean were 0.67 and 0.71, respectively. The regression of observed values against ones predicted from the no-intercept model had an intercept of 15.2 (S.E. = 8.84) and slope of 0.90 (S.E. = 0.062) that did not differ ($P > 0.05$) from 0 and 1, respectively. Residual plots are given in Fig. 4, for equations with (A) and without the intercept (B).

4. Discussion

4.1. Comparisons with other estimates

The assumed k_{pm} of 1.0 (AFRC, 1993) resulted in a MP_1 requirement and milk protein efficiency that agree more closely with values for other ruminant species compared with the k_{pm} of 0.67 (NRC, 1989).

Likewise, Luo et al. (2004b,c) reported MP requirements for growing and Angora goats based on a k_{pm} of 1.0 because of unrealistic estimates with the $0.67k_{pm}$. Thus, the no-intercept version of Eq. (2) appears to best describe the MP₁ requirement of lactating goats. The MP₁ requirement of 1.45 g/g milk protein is in close agreement with the milk protein efficiency of 0.68 (MP₁ requirement of 1.47 g/g milk protein) recommended by AFRC (1998), which was based on findings with other ruminant species (AFRC, 1992). However, AFRC (1998) reviewed a small number of reports with goats in which protein requirements were addressed, noting values similar to the recommendation. This finding and the large number of observations in the present study on which the MP₁ requirement of 1.45 g/g milk protein is based supports a similar MP₁ requirement for goats as for other ruminant species, and also suggests that assumptions used to determine the requirement were appropriate.

The observed milk protein efficiency estimate of 0.69 is similar to the value of 0.75 for the PDI (i.e., protéine digestible dans l'intestin) system of INRA (1989). An efficiency for use of absorbed N of 0.69 was suggested by Cizuk and Lindberg (1988). NRC (1989) and ARC (1980) employed milk protein efficiencies for lactating dairy cattle of 0.70 and 0.75, respectively. Milk protein efficiency estimates for goats based on digested CP are more variable. Brun-Bellut et al. (1986) cited by Brun-Bellut et al. (1987) reported a value of 0.78, although considerably lower values have been noted, such as 0.22–0.28 (Hussain et al., 1996), 0.29–0.31 (Sanz Sampelayo et al., 1998), 0.30–0.39 (Santini et al., 1992), 0.38 (Qi et al., 1992), 0.38–0.55 (Brun-Bellut et al., 1990) and 0.55 (Cizuk and Lindberg, 1988).

4.2. Unexplained variability

Although the MP₁ requirement derived from this approach is comparable to other estimates and recommendations for goats, there was considerable variability not accounted for. However, considering the various experimental conditions under which these observations used to derive the requirement were determined, perhaps the proportion of variability that was explained is relatively high. In order to maximize the number of observations, some reports with rela-

tively short experimental periods were used, for which variability in BW change due to previous conditions may have been greater than with longer feeding periods. Another consideration is the detail in which diets were described, which would influence the accuracy that MP intake was calculated with. Experiments specifically designed to determine the MP₁ requirement might result in greater explained variability, but would not have as broad of application as an estimate from a study such as this one with its large number of observations from many different production settings.

With the approach used to determine the MP₁ requirement, an inherent assumption is that MP₁ limited milk protein yield. It is possible that for some observations ME intake was relatively more limiting than intake of MP, which would have contributed to variability in milk protein yield not accounted for by MP₁. 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 MP₁ requirement was determined from change in MP₁ per unit change in milk protein yield, it seems appropriate to consider this MP₁ requirement a maximum rather than average and, relatedly, that supplying additional MP₁ as a safety factor to ensure desired levels of performance is unwarranted.

Some of the assumptions employed to estimate MP₁ may have contributed to variability not accounted for. For example, systems of protein evaluation rely on deterministic equations for estimating microbial protein synthesis, which have been derived using various microbial markers. The NRC (1985) equation is largely based on experiments using diaminopimelic acid or RNA as a microbial marker. Compared with ¹⁵N, diaminopimelic acid has underestimated microbial protein synthesis by 14% (Rohr et al., 1986). ARC (1980) data, which are the basis for the equation used to predict microbial protein synthesis of AFRC (1992, 1998) used in this study, relied upon microbial yield determined with various markers (i.e., diaminopimelic acid, RNA and ³⁵S), some of which relative to ¹⁵N could either underestimate or overestimate microbial yield. It is, therefore, possible that some unexplained variation in the relationship between MP₁ and M_kP yield is inseparably associated with the microbial markers used.

MkP was not partitioned into true and nonprotein N. Nonprotein CP in milk has been reported as 3.7–5.4% (Fernandez et al., 1997), 2.7–3.6% (Sahlu et al., 1999) and 2.5–10.7% (Lu et al., 1990a,b) of total CP. It is possible that MP₁ does not have the same effect on milk yield of nonprotein N as of true protein, with other dietary characteristics perhaps having relatively greater influence on milk yield of nonprotein N. For example, for observations where milk nonprotein CP was reported ($4.7 \pm 2.05\%$; $n = 13$), there was a weak tendency for a relationship with nonprotein ruminally degraded CP ($r = 0.42$; $P < 0.11$).

Another factor that undoubtedly contributed to unexplained variability in MkP is the protein content of BW change. For example, it is common for lactating animals to have positive tissue protein retention yet be in negative energy balance (Haque et al., 1988; Aguilera et al., 1990; Prieto et al., 1990; Sastradipradja et al., 1994). Similarly, the protein content of BW change may vary with stage of lactation and parity, which could not be addressed in this study because of insufficient relevant information in many reports. Also, efficiencies of MP use for tissue gain and of mobilized protein for MkP synthesis different from those assumed may have had influence.

Temporal changes in nutrient supplies to the goat mammary gland might contribute to unexplained variation in the relationship between MkP and MP₁. For efficient functioning of ribosomal organelles engaged in milk protein synthesis, it is envisaged that continual supplies of amino acids, energy and necessary co-factors are required. Consequently, deficiencies in any of these factors could either slow down the process or result in the synthesis of unwanted proteins that are rapidly degraded in the cell by ubiquitin (Stryer, 1988; Nelson and Cox, 2002), which both would decrease efficiency. Given that roughage and concentrate components of diets are frequently offered separately, and often lactating goats are fed concentrate not more than a few times daily, the composition of amino acids supplied at the tissue level might incur temporal changes, with appropriate and less than optimal quantities and arrays at different times of the day. Because there is no appreciable storage system for amino acids used in MkP synthesis, imbalances can only be averted or minimized through breakdown of tissue protein.

Assumptions of maintenance protein losses (i.e., metabolic fecal, endogenous urinary and scurf) were

assumed constant relative to MkP, some of which might rather be expected to increase with increasing MkP. Also, in mid-to-late lactation, milk yield decreases because of physiological and cytological changes, resulting in a decreased number of cells engaged in milk synthesis (Davis, 1997; McFadden, 1997) and perhaps reduced ribosomal activity. In addition, after early lactation there is increased partitioning of energy and nutrients to energy storage and support of pregnancy, which could lessen amino acids available for MkP, thus depressing efficiency of MkP production.

5. Summary and conclusions

A database of treatment mean observations was constructed from available goat feeding and nutrition research publications. MP₁ was determined by applying assumptions of CP degradability properties and RFE of dietary ingredients and partitioning of protein used for maintenance functions and lost or gained as BW. Regression of MP₁ against MkP indicated 1.45 g of MP₁ required per 1 g of MkP, or a milk protein efficiency of 0.69. Because of the appreciable size of the database used to derive these estimates, they should be of value in describing MP₁ needs of goats as well as predicting performance.

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