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Prediction of endogenous urinary nitrogen of goats

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Abstract

Three databases were constructed to estimate endogenous urinary N (EUN) in nonlactating and lactating goats. The first database consisted of 22 observations in which urinary N (UN) was measured with nonlactating goats fed diets very low in N concentration (0.032–0.33% of DM). A log-log weighted linear regression of EUN (g) on BW (kg) indicated that 0.75 was an appropriate power of BW for which UN, the estimate of EUN, could be expressed. The intercept, which represented an estimate of EUN, was 0.122 g/kg $BW^{0.75}$. The second database for nonlactating goats, with means from 186 treatment-experiment combinations, was split into two groups, one for equation development ($n = 121$) and a second for evaluation of the equations ($n = 65$). With the development set, UN (g/kg $BW^{0.75}$) was regressed on total N intake (TNI; g/kg $BW^{0.75}$) or apparently digested N intake (DNI; g/kg $BW^{0.75}$). After removing observations with relatively high residual S.D. from the development set, equations were: $UN = 0.092 + (0.288 \times TNI)$ ($n = 79$; $R^2 = 0.59$) and $UN = 0.165 + (0.340 \times DNI)$ ($n = 79$; $R^2 = 0.59$). The intercepts, 0.092 and 0.165 g/kg $BW^{0.75}$, are estimates of EUN when TNI and DNI are zero, respectively. At zero DNI, truly digested N intake should equal metabolic fecal N; thus, the DNI estimate of EUN may be applicable to nonlactating goats in zero or positive N balance with feed intake above maintenance and appropriate to use in summation equations to predict N requirements without need for further adjustment factors. Prediction equations for lactating goats with feed intake above maintenance were: $UN = 0.182 + (0.235 \times TNI)$ ($n = 33$; $R^2 = 0.65$) and $UN = 0.160 + (0.354 \times DNI)$ ($n = 33$; $R^2 = 0.72$). In summary, based on databases from publications on goat feeding and nutrition, EUN of nonlactating goats with feed intake above maintenance was estimated at 0.165 g/kg $BW^{0.75}$ by regressing UN against DNI; EUN of lactating goats based on DNI seemed similar to that for nonlactating goats.

Keywords: Goats; Nitrogen; Endogenous urinary nitrogen

1. Introduction

Endogenous urinary N (EUN) represents the minimal excretion of N. It is an inevitable loss, arising

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from incomplete recovery of N-containing compounds derived from turnover of tissue protein. Forms of EUN include urea, creatinine, bilirubin, allantoin, hippuric acid, uric acid and amino acids such as 3-methyl-histidine (SCARM, 1994). EUN can be estimated in several ways. First, EUN is considered equal to urinary nitrogen (UN) of animals fed diets very low in N concentration but adequate in energy and other nutrients; such diets must be consumed for an extended period of time because UN decreases gradually (Swanson, 1982). EUN also has been estimated as the intercept of regressions of UN against N supply (e.g., intake of total N (TNI) or of apparently digested N (DNI)). However, these estimates might be better described as inevitable UN loss because they can be altered by dietary and physiological factors (Owens, 1987).

EUN generally is considered to be related to energy metabolism; thus, EUN frequently is scaled to metabolic size, e.g., $BW^{0.75}$. On this basis, Brody (1945) described EUN for different animal species as EUN (g) $= 0.146 \times BW^{0.72}$. Conversely, a log–log regression used by Swanson (1982) for cattle fed low-N or N-free diets resulted in the equation EUN (g) $=$ $0.44 \times \text{kg}\,BW^{0.50}$. Likewise, NRC (1984) listed various relationships between EUN and BW of cattle. Brody (1945) suggested that most accurate powers of BW might differ among animal species.

EUN estimated by the low-N diet technique and via regression can differ. For example, because of differing amino acid composition of tissues being mobilized to support function of other essential organs and tissues (MacRae, 1996), UN with low-N diets might not correspond to UN arising only from turnover of tissue protein when N intake is adequate for maintenance (Owens, 1987). Likewise, EUN estimated via TNI versus DNI should differ. The estimate of EUN based on DNI is UN at a TNI when intake of truly digested protein equals metabolic fecal N. Conversely, UN at zero TNI (negative DNI) is associated with low tissue protein turnover (Millward et al., 1975; McDonald et al., 1977), with extensive N recycling and high tissue mobilization, in part to support metabolic fecal N loss (Swanson, 1982). Choice of different estimates of EUN should depend on the intended use, such as empirical equations to determine N requirements for various animal and production or experimental settings via the factorial approach, in which N losses, accretion in tissues and secretion in milk are summed (McDonald et al., 1977).

Relatively little research has been conducted to quantify EUN of goats, which is necessary for use of the factorial method of describing N requirements. Published reports with goats of different breeds and production stages indicate that EUN estimates vary widely, from 0.038 to 0.237 g/kg $BW^{0.75}$. Therefore, we compiled and evaluated literature on goat feeding and nutrition to estimate the EUN of nonlactating and lactating goats.

2. Materials and methods

2.1. Database construction

Three databases were constructed from a review of publications on goat feeding and nutrition published between 1951 and March, 2001. All presented data in these publications were included in the databases; however, in many instances, some data necessary for use in specific equations, such as BW, were not provided.

2.2. Database 1

The first database was constructed from five experiments conducted in India and Malawi (Table 1; Appendix A). The studies involved four goat breeds consuming low-N diets. EUN was considered to equal UN when it became minimal and presumably constant. Proc Reg of SAS (1990) was used to regress the $\log_{10}$ of EUN on the $\log_{10}$ of BW. The database included some observations from individual animals; therefore, the regression was weighted by the number of observations that comprised a mean.

2.3. Database 2

The second database was constructed from 49 different publications from 1960 to 2001 that reported data from N balance experiments (Table 1; Appendix B). These included 186 treatment means, with an average of five observations per treatment (range of 1–12). There were 12 named goat breeds and a number of undefined local types, for a total of 899 goats. Observations of database 1 also were

Table 1
Summary of databases used to predict endogenous urinary nitrogen of goats

Item	Database 1					Database 2					Database 3				
	n	Mean	S.D.	Minimum	Maximum	*n*	Mean	S.D.	Minimum	Maximum	*n*	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	22	40.5	11.41	28.3	67.0	186	26.4	12.99	5.5	67.0	52	50.8	15.39	20.0	68.3
DM intake (g/day)	22	779	267.9	364	1247	172	732	368.3	52	1740	69	1767	615.3	335	3070
CP (% DM)	18	1.30	0.616	0.18	2.06	155	12.9	5.25	0.2	28.8	67	14.2	2.77	7.2	19.9
N intake (g/day)	18	1.71	1.167	0.22	4.12	186	12.8	8.11	0.2	41.5	74	40.2	17.37	8.7	89.6
Digestible N intake (g/day)	18	−1.69	1.015	−3.63	−0.70	186	8.36	5.881	−3.34	29.55	74	27.0	12.64	6.5	65.4
Urinary N (g/day)						186	4.96	3.616	0.40	22.60	74	11.9	6.19	2.4	32.6
Milk N (g/day)											74	10.9	6.03	0.5	26.8
Endogenous urinary N (g/day)	22	1.94	0.434	1.48	2.86										

included in database 2. Table 2 lists the biotype, breed, number of goats, total number of treatments, dietary forage percentage and source or reference used in EUN prediction for nonlactating goats.

The database was split by randomized reference number as recommended by Moore et al. (1999) into two sets, one to develop prediction equations and the other for evaluation of the equations developed. Data in the two sets were as homogeneous as possible. Mean, minimum and maximum values for most variables were similar (Table 3). To increase variability explained by equations with this database, the standard deviation of residuals was used to identify and exclude observations not close to predicted values. The standard deviation of residuals chosen to identify observations to be omitted increased coefficients of determination and excluded a minimal number of observations. Regression equations were derived from regressing UN against N intakes, and differences in intercepts and slopes were tested (Miliken, 1984). These equations were used to predict UN in the evaluation set. Observed values were regressed on those predicted to determine if intercepts and slope differed from 0 and 1, respectively (Montgomery and Peck, 1982), with an intercept of 0 and slope of 1 indicating no obvious deviation or bias. To improve the coefficient of determination of equations, other variables that might account for variation in UN were evaluated by the R^2 and CP statistics (MacNeil, 1983) with Proc REG of SAS (1990).

2.4. Database 3

The third database was formed from 15 publications on lactating goats published from 1984 to 2000 (Table 1; Appendix C). There were 74 treatment means in this database, although only 52 of these provided BW values, for a total of 336 goats. This database included major dairy breeds in the world (e.g., Saanen, Alpine, Damascus), local breeds (e.g., Spanish, Granadina) and undefined breeds. Each of these experiments was conducted under confined feeding conditions, and N balance periods were 15–28 days in length. Milk production and stages of lactation were not specified for many observations. Table 4 lists biotype, breed, number of goats, total number of treatments, dietary forage percentage and source or reference used in EUN prediction for lactating goats.

Table 2
Summary of references used to predict endogenous urinary nitrogen of nonlactating goats

Biotype	Breed	Country[a]	BW (kg)	Goats[b]	Treatments[c]	Forage[d] (%)	Source
Dairy	Alpine	USA	38.5	7	1	69.6	Randy et al., 1984
	Alpine	USA	15.2	10	2	57.2	Beede et al., 1986
	Alpine	USA	23.8	32	4	50.0	Qi et al., 1993
	Alpine	France	51.3	3	1	100.0	Baracos et al., 1991
	Saanen	USA	26.5	16	3	100.0	Gelaye et al., 1990
	Saanen	Japan	44.1	9	3	91.5	Khan et al., 1998
	Nubian	USA	18.9	24	3	70.0	Richards et al., 1994
	Granadina	Spain	28.2	32	4	79.0	Prieto et al., 1990
	Alpine × Beetal	India	50.9	8	2	85.4	Kurar and Singh, 1982
	Alpine × Beetal	India	32.8	16	4	62.5	Rai and Mudgal, 1988
	Damascus × Baladi	Saudi Arabia	18.0	12	2	36.4	Abdel-Rahman and El Kaschab, 1996
	Toggenburg, Saanen	USA	21.2	28	4	48.2	Beede et al., 1985
	Alpine, Saanen	France	51.5	26	8	45.1	Brun-Bellut, 1997
	Jamnapari	India	33.4	24	4	60.0	Srivastave and Sharma, 1998
	Jamnapari	India	37.6	8	2	100.0	Majumdar, 1960
	Swedish Landrace	Sweden	7.9	24	8	0.0	Lindberg, 1989
Indigenous	West African goat	Nigeria	16.5	16	4	27.3	Onwuka and Akinsoyinu, 1989
	West African goat	Nigeria	7.8	12	3	25.0	Adeloye and Yousouf, 2001
	West African goat	Nigeria	7.5	15	3	100.0	Bamikole et al., 2001
	Spanish	USA	40.0	24	6	100.0	Dick and Urness, 1991
	Spanish	Mexico	33.6	12	3	100.0	Ramirez, 1997
	Scottish cashmere	UK	39.2	10	2	60.0	Souri et al., 1997
	Australian cashmere	Australia	16.9	16	4	5.6	Galgal and Norton, 1991
	Native goat	Guyana	21.7	41	9	31.5	Lallo, 1996
	Black Bengal	India	47.2	10	10	49.5	Rajpoot et al., 1980
	Black Bengal	India	19.6	8	2		Girdhar et al., 1991
	Black Bengal	India	7.6	10	2	100.0	Panda et al., 1983
	Native goat	Thailand	24.3	48	4	40.0	Cheva-Isarakul and Rengsirikul, 1991
	Black Bengal × Beetal	India	10.7	20	4	41.1	Virk et al., 1994
	Anglo-Nubian × native goat	Thailand	18.8	48	7	11.0	Pralomkarn et al., 1995
	Ibex	Israel	15.0	16	4		Degen et al., 1997
	Malawi goat	Malawi	29.9	16	4	69.0	Reynolds, 1981
	Native goat	Japan	25.9	16	4	63.9	Islam et al., 2000
	Mamber goat	Israel	34.4	10	2	100.0	Perevolotsky et al., 1993
	Etawah goat	Indonesia	26.1	27	3	19.1	Katipana and Sastradipradja, 1994
	Etawah goat	Indonesia	13.8	20	5		Astuti et al., 1997
	Dwarf goat	Cameroon	11.6	12	4	47.2	Njwe, 1992
	Desert goat	Sudan	21.0	10	2	38.0	El-Hag et al., 1985
	Native goat	Morocco	20.0	16	2	100.0	Narjisse et al., 1995
	Maradi goat	Nigeria	11.4	8	2	80.0	Adeloye, 1995
	Maradi goat	Nigeria	20.7	24	4	31.2	Adu et al., 1987
	Maradi goat	Nigeria	21.2	16	8		Mba et al., 1975
Mohair	Angora	USA	20.1	12	4	48.5	Qi et al., 1994
	Angora	USA	31.7	4	1	100.0	Nunez-Hernandez et al., 1991
	Angora	USA	45.4	32	4	78.2	Qi et al., 1992
	Angora	USA	41.0	18	3	95.0	Villena and Pfister, 1990
	Angora	USA	33.0	32	4	100.0	Boutouba et al., 1990

Table 2 (*Continued*)

Biotype	Breed	Country[a]	BW (kg)	Goats[b]	Treatments[c]	Forage[d] (%)	Source
	Angora	USA	27.1	25	5	43.7	Shenkoru et al., 2001
	Angora	UK	33.1	10	4	60.0	Souri et al., 1998
	Angora	New Zealand	29.9	6	1	100.0	Domingue et al., 1991

[a] Country where the experiment was conducted.
[b] Number of goats in the experiment.
[c] Number of treatments in the experiment.
[d] When not listed, sufficient information on dietary forage percentage was not reported.

Table 3
Summary of development and evaluation data sets of Database 2 for prediction of endogenous urinary nitrogen of nonlactating goats with feed intake above maintenance

Item	Development set					Evaluation set				
	n	Mean	S.D.	Minimum	Maximum	*n*	Mean	S.D.	Minimum	Maximum
Mean BW (kg)	121	24.9	11.84	5.5	61.5	65	29.2	14.65	6.9	67.0
DM intake (g/day)	110	723	356.2	52	1740	62	747	391.2	207	1693
CP (% DM)	95	13.5	4.42	1.0	20.0	60	11.7	5.91	1.5	28.8
N intake (g/day)	121	12.8	7.79	0.2	41.5	65	12.8	8.71	0.9	39.3
Digestible N intake (g/day)	121	8.47	5.706	−3.34	27.56	65	8.16	6.24	−1.12	29.55
Urinary N (g/day)	121	4.98	3.695	0.45	22.60	65	4.93	3.492	0.40	15.70

Table 4
Summary of references used to predict endogenous urinary nitrogen of lactating goats

Biotype	Breed	Country[a]	BW[b] (kg)	Goats[c]	Treatment[d]	Forage (%)	Source
Dairy	Alpine	France	62.7	108	9	70.0	Schmidely et al., 2002
	Alpine	Italy	51.9	28	2	50.0	Andrighetto and Bailoni, 1994
	Alpine	USA	54.3	12	3	44.0	Qi et al., 1992
	Alpine	France	53.3	3	1	94.1	Baracos et al., 1991
	Alpine	France		32	4	60.0	Schmidely et al., 1999
	Alpine	France		55	5	13.0	Brun-Bellut et al., 1990
	Alpine	USA		6	3	33.0	Barnes and Brown, 1990
	Saanen	Italy		27	3	56.1	Badamana et al., 1990
	Saanen	UK		12	3	56.0	Badamana and Sutton, 1992
	Damascus	Cyprus		4	2	40.5	Hadjipanayiotou, 1984
	Damascus	Cyprus		8	2	26.9	Hadjipanayiotou, 1988
	Damascus	Cyprus	62.2	56	17	24.1	Hadjipanayiotou, 1988
	Granadina	Spain	34.5	70	6	39.7	Aguilera et al., 1990
	Alpine, Saanen	France	50.2	19	6	44.5	Brun-Bellut, 1997
Indigenous	Etawah goat	Indonesia	20.0	20	4	55.1	Kiranadi et al., 1994
	Etawah goat	Indonesia	21.5	20	4	55.5	Sastradipradja et al., 1994

[a] Country where the experiment was conducted.
[b] Mean body weight of goats for all treatments. When not listed, sufficient body weight information was not reported.
[c] Number of goats in the experiment.
[d] Number of treatments in the experiment.

Because the number of treatment means was limited, this database was not divided. After testing for curvilinear regressions (quadratic and cubic) and removing observations that did not agree will with predicted values as for database 2, UN was linearly regressed on TNI and DNI, and differences in intercepts and slopes were tested as noted earlier.

3. Results

3.1. Database 1—BW power for EUN of nonlactating goats

Brody (1945) indicated that basal UN loss or EUN is proportional to a power of BW that can be determined by the power equation of $Y = aX^b$, with b potentially differing among animal species. Using Database 1, the log–log regression (Fig. 1), with EUN in grams and BW in kilograms, was:

$$\log \text{EUN} = -0.913(\text{S.E.} = 0.093) + (0.748(\text{S.E.} = 0.060) \times \log \text{BW}), \quad R^2 = 0.89 \tag{1}$$

The antilog of the intercept resulted in a prediction equation of EUN (g) $= 0.122$ g/kg BW$^{0.75}$. Because the exponent for BW was very close to the estimate of metabolic size used routinely in assessing energy requirements (0.75), this adjustment for BW was used in all further regressions.

3.2. Database 2

3.2.1. EUN of nonlactating goats

Using all data of the development set of Database 2, regressions of UN against TNI or DNI (g/kg BW$^{0.75}$) were:

$$\text{UN} = 0.116(\text{S.E.} = 0.043) + (0.279(\text{S.E.} = 0.033) \times \text{TNI}), \quad n = 121; \; R^2 = 0.38 \tag{2}$$

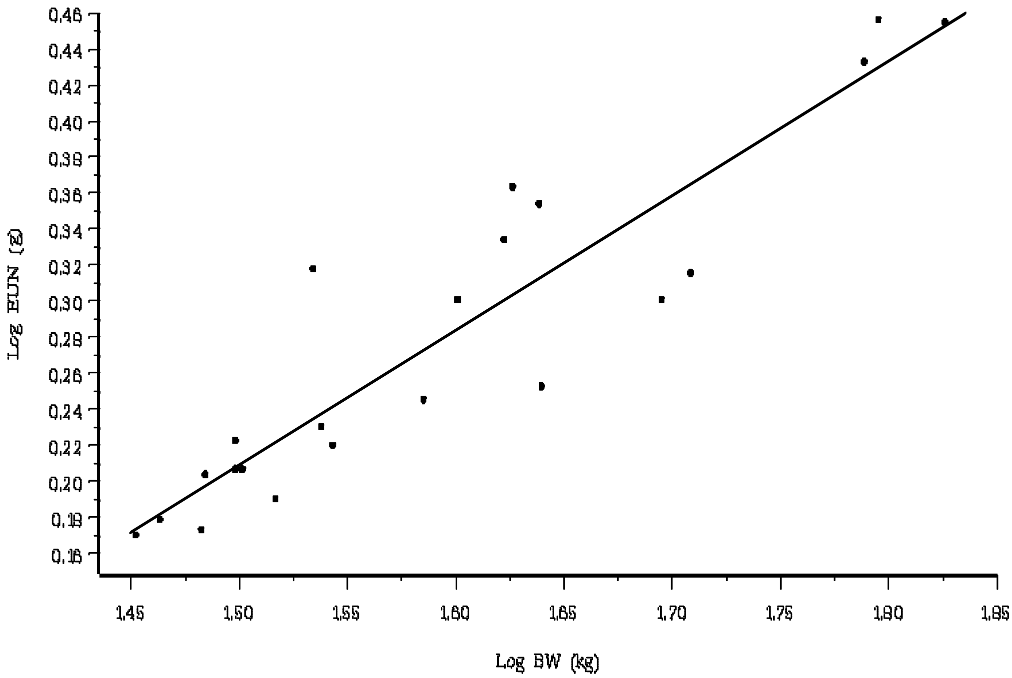

Fig. 1. The relationship between the log of endogenous urinary N (EUN) and the log of BW for nonlactating goats (Database 1). Points are observed values and the line describes the equation: $\log \text{EUN} = -0.913(\text{S.E.} = 0.093) + (0.748(\text{S.E.} = 0.060) \times \log \text{BW})$ ($n = 22$; $R^2 = 0.89$).

$$\mathrm{UN} = 0.197(\mathrm{S.E.} = 0.039) + (0.316(\mathrm{S.E.} = 0.043) \times \mathrm{DNI}), \quad n = 121; \; R^2 = 0.31 \tag{3}$$

Because of low coefficients of determination, plots of residuals against predicted EUN values were examined to identify observations with large residual S.D. These typically were associated with very high dietary CP concentrations, low intakes of forage and undefined indigenous goat breeds; however, some observed values from diets high in CP or low in forage fell close to predicted values. There were 32 and 37 observations for TNI and DNI equations, respectively, with residual S.D. greater than 1; 27 were common to both equations. To compare the two equations, observations omitted from one equation also were excluded from use in the other regardless of the residual S.D. This process resulted in 42 observations being removed. Revised regression equations were:

$$\mathrm{UN} = 0.092(\mathrm{S.E.} = 0.031) + (0.288(\mathrm{S.E.} = 0.027) \times \mathrm{TNI}), \quad n = 79; \; R^2 = 0.59 \tag{4}$$

$$\mathrm{UN} = 0.165(\mathrm{S.E.} = 0.025) + (0.340(\mathrm{S.E.} = 0.032) \times \mathrm{DNI}), \quad n = 79; \; R^2 = 0.59 \tag{5}$$

Intercepts and slopes of these two equations differed ($P < 0.07$ and 0.01, respectively). Eqs. (4) and (5) (shown as lines) and observed UN values are presented in Figs. 2 and 3, respectively. Coefficients of determination were improved by removing observations with high residual S.D., and EUN estimates with TNI and DNI equal to 0 were lower than before removal of observations (Eqs. (2) and (3), respectively).

To evaluate these prediction equations, observed values of UN in the evaluation data set were regressed against predicted values. Intercepts and slopes of both Eqs. (4) and (5) were not different from 0 ($P > 0.70$) and 1 ($P > 0.30$), respectively. Therefore, these equations seem to be unbiased estimates of EUN and UN for nonlactating goats.

3.2.2. UN of nonlactating goats

To predict total UN, multiple regression models including predicted UN from Eqs. (4) and (5) (EXUN_4 and EXUN_5, respectively) were developed that included additional variables available for most observations (e.g., dietary levels of forage (FC) and CP (CPC) and apparent N digestibility). Including FC and CPC (%) resulted in small improvements in R^2 and the root mean square error, although numbers of observations were less than for Eqs. (4) and (5). These equations, with all variables scaled to $\mathrm{BW}^{0.75}$,

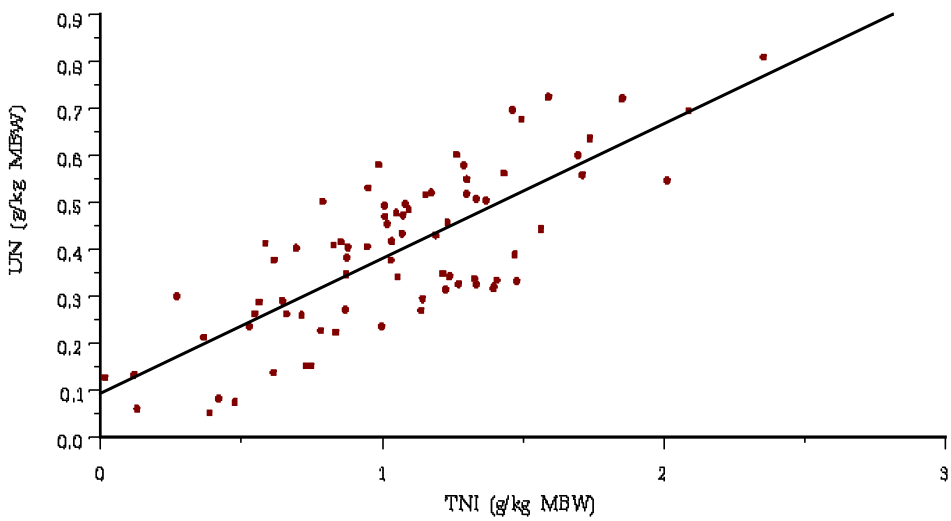

Fig. 2. The relationship between urinary N (UN) and total N intake (TNI) for nonlactating goats (Database 2). Points are observed values and the line describes the equation: UN = 0.092(S.E. = 0.031) + (0.288(S.E. = 0.027) × TNI) ($n = 79$; $R^2 = 0.59$). MBW=$\mathrm{BW}^{0.75}$.

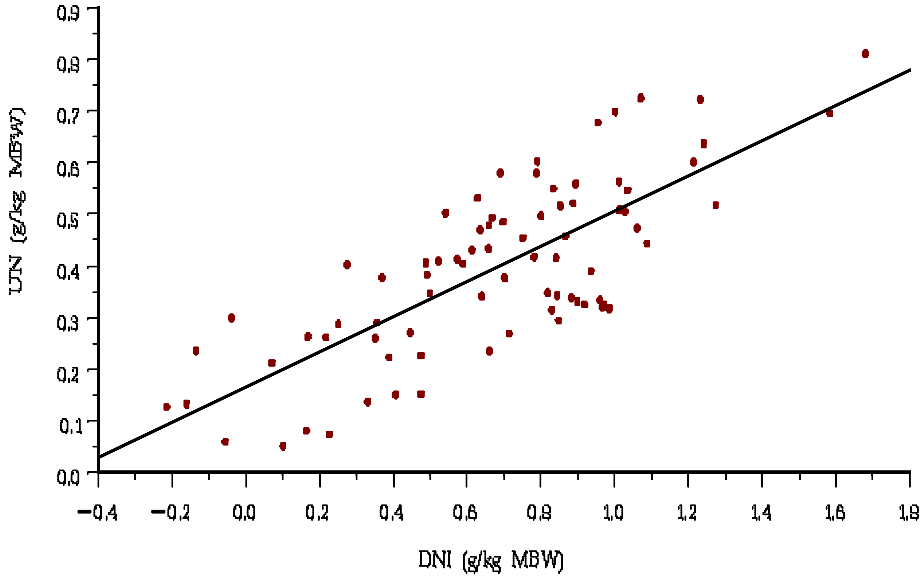

Fig. 3. The relationship between urinary N (UN) and apparently digested N intake (DNI) for nonlactating goats (Database 2). Points are observed values and the line describes the equation: UN = 0.165(S.E. = 0.025) + (0.340(S.E. = 0.032) × DNI) ($n = 79$; $R^2 = 0.59$). MBW = $BW^{0.75}$.

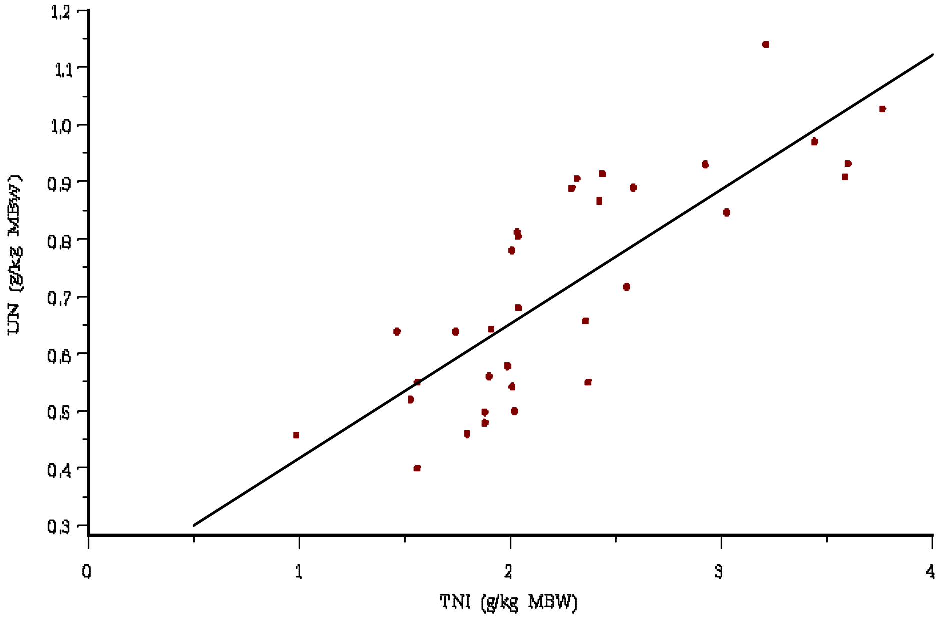

Fig. 4. The relationship between urinary N (UN) and total N intake (TNI) for lactating goats (Database 3). Points are observed values and the line describes the equation: UN = 0.182(S.E. = 0.073) + (0.235(S.E. = 0.031) × TNI) ($n = 33$; $R^2 = 0.65$). MBW = $BW^{0.75}$.

were:

$$\mathrm{UN} = -0.104(\mathrm{S.E.} = 0.061) + (1.251(\mathrm{S.E.} = 0.141) \times \mathrm{EXUN}_4) - (0.070(\mathrm{S.E.} = 0.025) \times \mathrm{CPC}) + (0.015(\mathrm{SE} = 0.006) \times \mathrm{FC}), \quad n = 62;\ R^2 = 0.63 \tag{6}$$

$$\mathrm{UN} = -0.103(\mathrm{S.E.} = 0.064) + (1.207(\mathrm{S.E.} = 0.142) \times \mathrm{EXUN}_5) - (0.044(\mathrm{S.E.} = 0.024) \times \mathrm{CPC}) + (0.013(\mathrm{SE} = 0.006) \times \mathrm{FC}), \quad n = 62;\ R^2 = 0.61 \tag{7}$$

3.3. Database 3—EUN of lactating goats

The initial regression of UN against N intakes with all observations of Database 3 yielded negative EUN values. Furthermore, inclusion of quadratic or cubic terms did not yield positive EUN. When individual observations were examined, it was evident that eight observations from two publications (Hadjipanayiotou, 1988; Sastradipradja et al., 1994), both with relatively low dietary N concentrations and low UN and N intake, diverged markedly from all other observations. These eight observations were removed, and regression equations were recalculated. From these equations, an additional 11 observations had residual S.D. greater than 1.25, and these were also omitted. Final equations were:

$$\mathrm{UN} = 0.182(\mathrm{S.E.} = 0.073) + (0.235(\mathrm{S.E.} = 0.031) \times \mathrm{TNI}), \quad n = 33;\ R^2 = 0.65 \tag{8}$$

$$\mathrm{UN} = 0.160(\mathrm{S.E.} = 0.065) + (0.354(\mathrm{S.E.} = 0.040) \times \mathrm{DNI}), \quad n = 33;\ R^2 = 0.72 \tag{9}$$

Intercepts were similar ($P < 0.83$) and slopes differed ($P < 0.07$). Eqs. (8) and (9) (shown as lines) and observed UN are shown in Figs. 4 and 5, respectively.

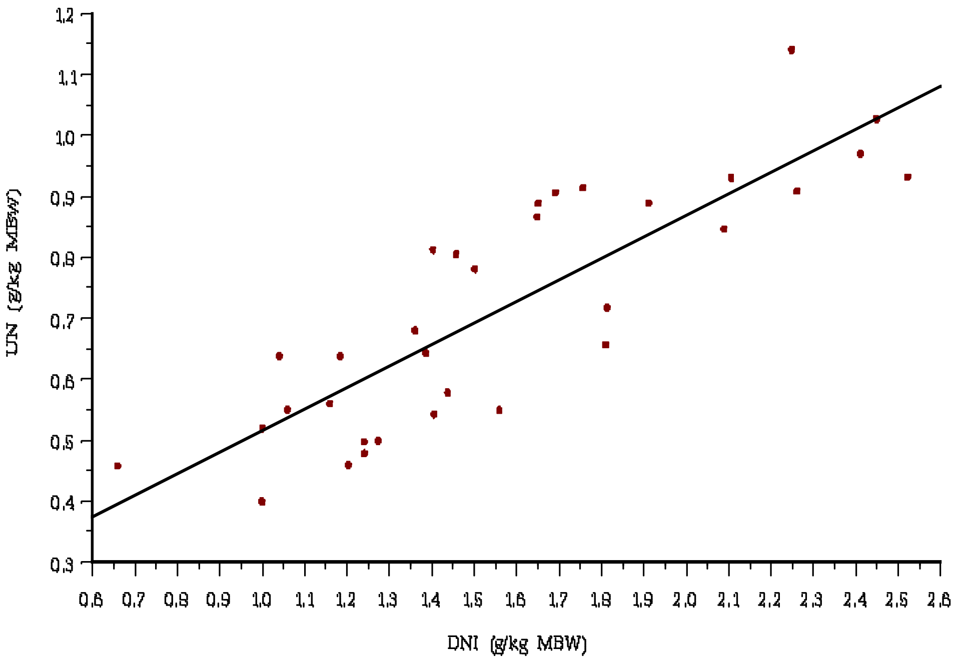

Fig. 5. The relationship between urinary N (UN) and apparently digested N intake (DNI) for lactating goats (Database 3). Points are observed values and the line describes the equation: UN = 0.160(S.E. = 0.065) + (0.354(S.E. = 0.040) × DNI) ($n = 33$; $R^2 = 0.72$) MBW = $BW^{0.75}$.

4. Discussion

4.1. Database 1—BW power for EUN of nonlactating goats

The relationship between EUN and BW of EUN (g) $= 0.146 \times BW^{0.72}$ was first established by Brody (1945) for all animal species. He stated that more accurate powers of BW might exist for certain animal species. For most animal nutrition studies, the BW power of 0.75 is termed metabolic BW or metabolic size because it appears linearly related to fasting heat production or basal metabolic rate. Thus, it may not be surprising that the log–log regression of database 1 identified 0.75 as an appropriate power of BW to express EUN of goats.

The EUN estimate from Eq. (1) of 0.122 g/kg $BW^{0.75}$, determined directly with goats fed low-N diets, was similar to the simple mean of EUN estimates of these experiments. Goats in Database 1 lost or maintained BW. Hence, this EUN estimate could be considered applicable to goats with feed intake below or near maintenance. Estimates of EUN in nonlactating goats with feed intake near maintenance have been quite variable. Itoh et al. (1978) estimated a daily loss of 0.237 g N/kg $BW^{0.75}$ in adult castrate native Japanese goats. Akinsoyinu et al. (1976) and Cheva-Isarakul and Rengsirikul (1991) reported values of 0.038 and 0.041 g/kg $BW^{0.75}$ for west African dwarf and native Thailand goats, respectively. EUN values similar to those of our summary have been reported. These include 0.115 g/kg $BW^{0.75}$ with four Indian goat breeds (Rajpoot et al., 1980), 0.119 g/kg $BW^{0.75}$ with Granadina goats (Prieto et al., 1990), 0.121 g/kg $BW^{0.75}$ with Malawi goats (Reynolds, 1981), 0.129 g/kg $BW^{0.75}$ with Jamnapari goats (Majumdar, 1960), 0.133 g/kg $BW^{0.75}$ with Malaysian Kambing Katjang goats (Devendra, 1982) and 0.113 and 0.123 g/kg $BW^{0.75}$ with French castrate goats (AFRC, 1998).

4.2. Database 2—EUN of nonlactating goats

4.2.1. Method of determination

Prieto et al. (1990) stated that EUN values are greater when calculated from regression than when estimated directly with low-N diets. Similar suggestions have been advanced for cattle (Patle and Mudgal, 1975) and sheep (Robinson and Forbes, 1966). This difference may result from greater metabolic activity and more normal physiological conditions of ruminants when consuming diets with moderate to high levels of N (Berdanier et al., 1967). Furthermore, EUN may decline as the duration of feeding a low-N diet progresses (Flurer et al., 1988), although this has not been detected in experiments with goats (Majumdar, 1960; Rajpoot et al., 1980; Reynolds, 1981). However, our finding of lower EUN from Eq. (4) (0.092 g/kg $BW^{0.75}$) than EUN from Eq. (1) (0.122 g/kg $BW^{0.75}$) does not agree with reports of greater EUN when determined directly than by regression. A plausible explanation for the difference we observed involves how well the profile of amino acids from protein being mobilized when low-N diets are fed matches with amino acid needs of vital organs and tissues to which amino acids are being directed (Owens, 1987). For example, body reserve proteins are low in sulfur-containing amino acids relative to amino acids required for continual synthesis of digestive enzymes and intestinal tissues (MacRae, 1996), possibly eliciting excess protein mobilization and amino acid catabolism and elevated urea excretion (Owens, 1987). Furthermore, the lower EUN of Eq. (4) compared with the EUN estimate of Eq. (1) suggests less excess amino acids in microbial protein available when TNI is adequate, as was the case for most observations of database 2, compared with mobilized protein when low-N diets are fed (Database 1; Eq. (1)). It should be noted, however, that extensive recycling of available urea to the digestive tract with low-N diets (Swanson, 1982; Silanikove, 2000) could restrict the impact on UN of differences in amino acid composition among absorbed protein and that in mobilized and vital maintenance tissues. Overall, for predicting N requirements of producing animals with zero or positive N balance through summation equations, EUN estimated by regression might be considered more appropriate than EUN estimated by the traditional low-N diet approach (Hendriks et al., 1997).

4.2.2. TNI versus DNI

The EUN of ruminants has been estimated by regressing UN against both DNI (Robinson and Forbes, 1966; Itoh et al., 1978; Pachauri and Negi, 1980a,b; Reynolds, 1981; Bhargava et al., 1985; Ciszuk and

Lindberg, 1985) and TNI (Patle and Mudgal, 1975; Aguilera et al., 1990; Cheva-Isarakul and Rengsirikul, 1991). Regression against TNI could be viewed as preferable, because TNI is positive when DNI is zero. Zero DNI should be TNI at which intake of truly digested protein equals metabolic fecal N; a regression of TNI against DNI (TNI = 0.296 (S.E. = 0.035) + (1.121 H DNI); $R^2 = 0.89$) indicated a TNI of 0.296 g/kgBW$^{0.75}$ at zero DNI. In accordance, EUN based on DNI was greater in Eq. (5) than when calculated from TNI (Eq. (4)). The difference in these estimates would have a considerable effect on calculations of CP requirements by the factorial method. For example, with a 30-kg goat consuming dietary DM at 3% of BW, true protein digestibility of 90% and biological value of consumed protein of 66%, the difference between EUN of Eqs. (4) and (5) equates to a dietary CP concentration of approximately 1% of DM.

Assumptions for calculating EUN by regression of UN against N intakes are constancy relative to the BW power and that the increase in UN above EUN is linear and in response to change in N intake. Curvilinearity in the relationship between UN and TNI or DNI has been observed in some cases (Itoh et al., 1978; Cheva-Isarakul and Rengsirikul, 1991); however, in the present study, there were not significant quadratic or cubic effects of TNI or DNI on UN. The linear increase in UN as TNI or DNI increased when DNI was above zero was expected, with UN increasing primarily because of increasing disposal of excess consumed N. Below zero DNI, the linear increase in UN might be explained by compensating or counteracting changes in the origin of UN and N recycling as N intake increased. When N intake is very low, N recycling is high; a considerable proportion of consumed and mobilized N below zero DNI is directed to the digestive tract, for maintenance and secretions of these vital tissues, and possibly to some extent for support of intestinal bacterial growth (Swanson, 1982; Silanikove, 2000). In this regard, metabolic fecal N is typically predicted from DM intake or fecal DM, and it is assumed independent of N intake. Hence, below zero DNI nitrogenous compounds from tissue protein turnover in UN are low relative to that with N intake above zero DNI, largely because below zero DNI many of these compounds are used to support metabolic fecal N loss and thus do not appear as UN (Swanson, 1982). As N intake increases up to zero DNI, UN may increase primarily because of increasing protein turnover (Millward et al., 1975), with relatively little impact of exogenous N on UN compared with change in N intake at higher levels.

The choice of EUN estimate (i.e., regression against TNI or DNI) should depend on the intended use. McDonald et al. (1977) suggested that assessing endogenous N losses with minimal N intake might not be applicable to losses when diets containing more protein are fed, implying that the DNI-based estimate could be more appropriate for employment in the classical factorial method of determining N requirements of goats in zero or positive N balance. To adequately describe the maintenance N loss from protein turnover in the body, being potentially added to metabolic fecal N to derive the total maintenance N requirement (not considering scurf N loss), it might be preferable to use an estimate of EUN at a TNI providing a level of truly digested protein equal to the maintenance N loss of metabolic fecal N. Use of the TNI-based EUN may represent the true minimal UN loss, but for utility it seems most applicable to goats in negative N balance, although as noted earlier it may not adequately consider less than optimal matching of the profile of amino acids in mobilized and maintenance tissues. Hence, addition of the EUN estimate from Database 1 or the EUN value of Database 2 based on TNI to an estimate of metabolic fecal N could underpredict the total maintenance N need of goats in zero or positive N balance.

4.2.3. Dietary forage and CP concentrations

The indication that EUN increases as the percentage of forage in the diet increases may reflect a decreased amount of ruminally fermented organic matter, less ruminal trapping of recycled ammonia and greater net ruminal ammonia absorption with increasing forage. However, no explanation is apparent for the negative regression coefficient for the dietary percentage of CP.

4.3. Database 3—EUN of lactating goats with feed intake above maintenance

Aguilera et al. (1990) suggested that EUN of lactating goats was greater than that of nonlactating goats and should be estimated independently. However, there have not been direct comparisons of EUN in lactating versus nonlactating goats. EUN is a maintenance loss, in this way similar to energy used achieve constant body energy content, with both typically described by a function of BW. In this regard, maintenance energy expenditures are suggested to be 20% greater for lactating than for nonlactating beef cows (NRC, 1996), and protein mobilization to meet energy and carbon requirements for milk synthesis will increase with level of milk production. However, increased maintenance expenditures due to lactation have not been detected in dairy cows (NRC, 2001).

Previous EUN estimates of lactating goats are 0.111 (Brun-Bellut et al., 1984), 0.218 (Aguilera et al., 1990), 0.229 (Ciszuk and Lindberg, 1985) and 0.17 g/kg $BW^{0.75}$ (Giger, 1987). Factors responsible for large differences among these estimates are unknown, although breed may be among them. In the present study, data used to predict EUN value in Database 3 were obtained from four goat breeds under various management conditions. Therefore, these findings would seem useful as a general estimate for lactating goats, but because of the limited number of observations and variability in experimental conditions, the estimates may not be appropriate for all types of goats in some situations, such as extreme environments or very low nutritional planes (Silanikove, 2000).

The difference between TNI and DNI estimates of EUN for lactating goats (Eqs. (8) and (9), respectively) was opposite of that for nonlactating goats (Eqs. (4) and (5)), although estimates were not significantly different ($P > 0.70$). N intakes were greater than in Database 2, which is understandable given the need for moderate or high N intakes to support milk production. In fact, there were no observations with zero or negative DNI. Also, the total number of observations was low relative to the number in Database 2. Hence, comparisons of these EUN estimates for lactating goats with those for nonlactating goats of Database 2 are difficult. Based on regressions of UN on TNI (Eqs. (4) and (8)), EUN would seem to be much greater for lactating versus nonlactating goats. This could reflect mobilization of body protein reserves to supply both energy and carbon demands of the active mammary gland. However, based on regressions of UN against DNI (Eqs. (5) and (9)), EUN of lactating goats may not differ markedly from that of nonlactating goats with zero or positive N balance. The DNI estimate was slightly less than for nonlactating goats, and the TNI estimate was only 10% greater than EUN for nonlactating goats based on DNI.

5. Summary and conclusions

EUN estimates for goats were obtained by regressions with data gleaned from publications on goat feeding and nutrition research. Based on experiments with low-N diets, an appropriate power of BW to express relationships between UN and N intakes was 0.75. The EUN by nonlactating goats with feed intake above maintenance was 0.092 g/kg $BW^{0.75}$ when determined by regression of UN against TNI and 0.165 g/kg $BW^{0.75}$ against DNI, with the latter value possibly most accurately predicting EUN for goats in zero or positive N balance. Because the database included a number of observations with low N intake and EUN may be lower with N intake less versus greater than needed for maintenance functions (EUN, metabolic fecal N and scurf), the lower estimate of EUN based on regression of UN against TNI could be most appropriate with N intake less than that for the sum of maintenance functions. Based on the regression of UN on DNI, EUN by lactating goats with feed intake above maintenance did not seem to differ markedly from that of nonlactating goats.

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Appendix A

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