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Voluntary feed intake by lactating, Angora, growing and mature goats

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Abstract

Databases amassed from the literature were used to predict feed intake by lactating, Angora, growing and mature goats, using 221, 54, 282 and 99 treatment means, respectively. One prediction approach was based on a calculated constant overall efficiency of ME utilization (k) considering biotype (meat, ≥50% Boer; dairy; indigenous; Angora), BW (kg; all goats), 4% fat-corrected milk (FCM, kg; lactating), BW change or ADG (kg; lactating, growing and mature), dietary ME concentration (MEC, MJ/kg DM; all goats), tissue gain (TG, kg; Angora) and clean mohair fiber gain (FG, kg; Angora). For lactating goats, assumptions included efficiency of ME utilization for maintenance and activity: $0.503 + (0.019 \times \text{MEC})$; efficiency of ME use for gain (k_g): 0.75; efficiency of use of mobilized ME for lactation: 0.84; efficiency of use of dietary ME for lactation: 0.589; tissue energy concentration (TEC): 23.9 MJ/kg; ME requirement for maintenance and stall or pen activity ($\text{ME}_\text{m}\text{REQ}$): 0.5013 and 0.4227 MJ/kg $\text{BW}^{0.75}$ for dairy and other goats, respectively; and all mobilized tissue energy used for lactation. After removing observations with residuals greater than 1.5 × root mean square error (RMSE), k was 0.653 (S.E. = 0.0014). Predicted DM intake (DMI_P) including an adjustment (DMI_AP) for the ratio of ADG:FCM (ADGFCM) was: DMI = 0.0964 (S.E. = 0.0704) + (0.9334 (S.E. = 0.9314) × DMI_P) − (0.1237 (S.E. = 0.05923) × ADGFCM) ($R^2 = 0.84$; RMSE = 0.2187; $n = 191$). Mean k, estimated from a random development data set, resulted in unbiased prediction of intake for an evaluation data set without observations removed. Assumptions for Angora goats that differed from lactating goats were efficiency of ME use for tissue gain (TG; kg/day): $0.006 + (0.0423 \times \text{MEC})$; efficiency of use of ME (dietary and mobilized tissue) for clean fiber gain (FG): 0.151; TEC = $4.972 + (0.3274 \times \text{kg BW})$; ME_m: 0.473 MJ/kg $\text{BW}^{0.75}$; ME used for FG: FG × 157 MJ/kg; and all mobilized tissue energy used for FG. Mean k for Angora goats was 0.525 (S.E. = 0.0112), and prediction accuracy was improved by adjusting for dietary CP concentration (PTCP,

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% DM): DMI = −0.1607 (S.E. = 0.11430) + (0.8227 (S.E. = 0.10851) × DMI_P) + (0.0199 (S.E. = 0.00697) × PTCP) (R^2 = 0.65; RMSE = 0.1239; n = 54). Assumptions for growing goats included: k_g: 0.006 + (0.0423 × MEC); efficiency of use of mobilized tissue energy for maintenance: k_m; and ME_mREQ: 0.489, 0.580 and 0.489 MJ/kg $BW^{0.75}$ for meat, dairy and indigenous goats, respectively. After removing observations with residuals greater than 2 × RMSE, k was 0.634 (S.E. = 0.0020). Prediction accuracy was improved by adjusting for ratios of ADG to BW (ADGBW), $BW^{0.75}$ (ADGMBW) and $ADGMBW^2$: DMI = −0.0047 (S.E. = 0.1854) + (0.9637 (S.E. = 0.04928) × DMI_P) − (70.27 (S.E. = 23.534) × ADGBW) + (38.71 (S.E. = 12.224) × ADGMBW) − (243.4 (S.E. = 121.73) × $ADGMBW^2$) (R^2 = 0.88; RMSE = 0.1030; n = 266). Mean k estimated from a random development data set resulted in unbiased prediction of intake for an evaluation data set without observations removed. Assumptions for mature goats were the same as those for growing goats except for a ME_mREQ of 0.462 MJ/kg $BW^{0.75}$. k was 0.632 (S.E. = 0.00448), and prediction accuracy was improved by adjusting for PTCP, ADGBW and ADGMBW: DMI = −0.1241 (S.E. = 0.07374) + (0.7915 (S.E. = 0.06911) × DMI_P) + (0.0214 (S.E. = 0.00381) × *PTCP*) − (535.2 (S.E. = 66.35) × ADGBW) + (247.3 (S.E. = 29.53) × ADGMBW) (R^2 = 0.85; RMSE = 0.1537; n = 99). Because of the relatively large number of observations in this study, these methods should be useful for predicting voluntary intake of different diets by a variety of goats in or near thermoneutral conditions fed in pens or stalls.

Keywords: Goats; Feed intake; Metabolizable energy; Prediction

1. Introduction

Voluntary feed intake substantially alters productivity of goats and other ruminants. Very few equations are available for predicting feed intake by goats. For lactating goats, AFRC (1998) proposed that an equation of INRA (1988) developed with diets based on corn silage, alfalfa hay and concentrates might be suitable. For fiber-producing and growing goats, because of limited information available, AFRC (1998) suggested that feed intake could be predicted from equations developed for sheep. For dairy-type stall-fed goats at maintenance, an equation of INRA (1988) for mature goats was recommended by AFRC (1998). Because no consistent approach for predicting intake by goats was available, this study was designed to develop methods for predicting feed intake by lactating, Angora, growing and mature goats based on a database of treatment means amassed from published literature. Factors used to predict intake were ones thought to be of major importance and that farmers should have knowledge of or that are accessible. The independent variables describing diets were concentrations of metabolizable energy and crude protein, and ones for animals were production state or type (i.e., lactating, mature, Angora and growing), body weight and production level (i.e., body weight change, milk production and composition, change in tissue mass and mohair fiber growth). A larger number of factors such as involving more detailed descriptions of animal and diet properties was not employed since this might limit the number of potential users.

2. Materials and methods

2.1. Lactating goats

Variables used in the models to predict feed intake by lactating goats (other than Angora) were mean BW (kg), biotype (unselected or genotypes selected for milk production; e.g., Saanen, Alpine, Damascus, Norwegian, Swedish Landrace and dairy crossbred), observed DM intake (DMI; kg), average daily gain or loss of BW (kg; ADGP and ADGN, respectively), dietary ME concentration (MEC; MJ/kg DM) and 4% fat-corrected milk (kg; FCM) production. Observations came primarily from Nsahlai et al. (2004), but when DMI did not seem to be ad libitum, means were removed. After adding observations from several more reports, a total of 36 reports with 221 treatment mean observations were compiled. Most assumptions employed were those of Nsahlai et al. (2004), which are listed below:

- k_m efficiency of ME utilization for maintenance: 0.503 + (0.019 × MEC; AFRC, 1998)
- k_g efficiency of ME use for tissue gain: 0.75 (NRC, 1989)
- k_{lt} efficiency of use of mobilized tissue energy for lactation: 0.84 (AFRC, 1998)

k_{ld} efficiency of use of dietary ME for lactation: Method 1: 0.624 (Nsahlai et al., 2004); Method 2: 0.589 (Nsahlai et al., 2004)
TEC concentration of energy in tissue mobilized or accreted: 23.9 MJ/kg (AFRC, 1998)
ME_m ME for maintenance and stall or pen activity (MJ), based on average BW during the experiment: Method 1: 0.3465 MJ/kg $BW^{0.75}/k_m$ (AFRC, 1998); Method 2: 0.5013 and 0.4227 MJ/kg $BW^{0.75}$ for dairy and other goats (Nsahlai et al. (2004) from estimates of Luo et al. (2004b))
ME_{lt} ME from mobilized tissue used for lactation (MJ): ADGN × TEC
NE_{lt} net energy for lactation from mobilized tissue (MJ): $ME_{lt} \times k_{lt}$
ME_g ME used for tissue gain (MJ): ADGP × TEC/k_g
NE_l net energy for lactation (MJ): FCM × 3.079 MJ/kg
NE_{ld} net energy for lactation from the diet: $NE_l - NE_{lt}$
ME_{ld} ME from the diet used for lactation: (MJ) NE_{ld}/k_{ld}
ME_{tot} total ME metabolized (MJ): $ME_m + ME_{lt} + ME_g + ME_{ld}$
ME_mPR ME_m as a proportion of ME_{tot}: ME_m/ME_{tot}
$ME_{lt}PR$ ME_{lt} as a proportion of ME_{tot}: ME_{lt}/ME_{tot}
ME_gPR ME_g as a proportion of ME_{tot}: ME_g/ME_{tot}
$ME_{ld}PR$ ME_{ld} as a proportion of ME_{tot}: ME_{ld}/ME_{tot}
k assumed constant overall efficiency of ME utilization: $(ME_mPR \times k_m) + (ME_{ld}PR \times k_{ld}) + (ME_gPR \times k_g) + (ME_{lt}PR \times k_{lt})$; mean k was then used in the following equation to predict metabolized energy (ME_{Ptot}; MJ): $ME_{Ptot} = ((ME_m \times k_m) + (ME_{ld} \times k_{ld}) + (ME_g \times k_g) + (ME_{lt} \times k_{lt}))/k$

MEI was predicted (MEI_P) by subtraction of ME_{lt} from ME_{Ptot}, and the amount of dietary DM (DMI_P) needed to provide MEI_P was estimated by dividing MEI_P by MEC.

This approach is similar to that used by Tolkamp and Ketelaars (1994), and is consistent with methods of NRC (2000). In Tolkamp and Ketelaars (1994), overall efficiency of ME utilization was estimated for lactating dairy cows and for growing/finishing beef cattle consuming diets ad libitum under practical production conditions to be approximately 0.60, based on efficiencies of ME utilization for different functions determined with limited intake. However, use of 0.60 in the present study did not predict DMI as accurately as k determined with this database. One factor that may have contributed to this is inclusion of the activity energy cost in ME_m, which also is relevant for Angora, growing and mature goats. This approach was used for Method 2 with lactating goats and for other types of goats because ME_m requirements were determined in companion studies for goats in pen or stall settings without an appropriate means of partitioning ME_m into that attributable to fasting heat production or NE_m and contributions of energy for activity and heat increment of maintenance. Furthermore, as indicated later, similar accuracy of prediction of intake by lactating goats between Methods 1 and 2 suggests that this approach is acceptable. Because of these factors, and the fact that k is a function of specific assumptions employed, we deemed it appropriate to use the mean k determined from our databases.

Actual DMI was regressed against DMI_P. Model fit was evaluated with R^2 and root mean square error (RMSE); an intercept not different from 0 and slope not different from 1 ($P > 0.05$) was taken to indicate that the prediction was not biased. To improve model fit and remove bias, observations with residuals (observed minus predicted values) greater than 2 or 1.5 × RMSE were removed. Mean k then was recalculated, with accompanying re-estimation of MEI_P and DMI_P. Reports with observations removed were studied for commonalties and unique characteristics.

Variables included in regressions of DMI against DMI_P with other databases did not have significant effects with lactating goats ($P > 0.10$). However, the ratio of ADG:FCM (ADGFCM) had a significant effect ($P < 0.05$); hence, it was included in the equation to adjust DMI_P (DMI_{AP}). After final regressions with the entire database, data sets were constructed randomly by report for equation development and evaluation (143 and 78 observations, respectively; Table 1). The same allocation of reports used by Nsahlai et al. (2004) was employed here, with random allotment of reports not used in this previous study. The development data set excluded observations with residuals greater than

Table 1
Mean, S.E., minimum and maximum values in development and evaluation data sets used for prediction of feed intake by lactating goats[a]

Item[b]	Development data set				Evaluation data set			
	Mean	S.E.	Minimum	Maximum	Mean	S.E.	Minimum	Maximum
BW (kg)	48.5	0.90	20.0	68.9	56.8	1.12	24.2	68.7
DM intake (kg/day)	2.07	0.051	0.30	3.54	2.21	0.064	0.80	3.61
DM intake (% BW)	4.30	0.086	1.02	6.69	3.92	0.106	2.70	6.27
FCM (kg/day)	2.28	0.088	0.08	5.47	2.73	0.119	0.43	4.97
ADG (g/day)	32	6.9	−192	372	29	7.0	−111	172
Dietary ME (MJ/kg DM)	10.4	0.09	6.3	12.9	10.8	0.11	7.3	12.9
ME intake (MJ/day)	21.5	0.54	1.66	36.4	23.8	0.62	5.8	33.8

[a] $n = 143$ and 78 for development and evaluation data sets, respectively.
[b] FCM = 4% fat-corrected milk.

1.5 × RMSE determined with the entire database. The evaluation data set, however, included all observations regardless of size of the residual. Mean k determined with the development data set was then used to determine MEI_P and DMI_P with the evaluation data set, with regression of DMI against DMI_P. In addition, multiple regressions of DMI against BW, FCM, MEC and ADG were conducted, as well as use of the equation recommended by AFRC (1998), based on INRA (1988): $DMI_P = (0.062 \times \text{kg BW}^{0.75}) + (0.305 \times$ kg 3.5% fat-corrected milk). ADGFCM did not have a significant effect ($P > 0.10$) when included in multiple regressions. Regressions were conducted using the REG and GLM procedures of SAS (1990).

2.2. Angora goats

Variables used to predict feed intake by mohair-producing Angora goats were mean BW (kg), average daily tissue loss or gain (kg, ADG minus grease fleece gain; TGN and TGP, respectively), clean fiber growth rate (kg/day; FG), MEC (MJ/kg DM) and dietary CP concentration (PTCP; % DM). Intake observations were those of Luo et al. (2004a) with values removed when intake did not appear to be ad libitum. Data from a small number of observations with lactating Angora goats were excluded, resulting in a database with 12 reports and 54 treatment means, summarized in Table 2. Many of the assumptions used earlier were employed here, which are listed below:

- k_m — efficiency of ME utilization for maintenance: $0.503 + (0.019 \times \text{MEC}$; AFRC, 1998)
- k_{tg} — efficiency of ME use for tissue gain: $0.006 + (0.0423 \times \text{MEC})$ (AFRC, 1998; mixed, unpelleted diet)
- k_{fg} — efficiency of use of ME from the diet and mobilized tissue for FG: 0.151 (Luo et al., 2004a)
- TEC — concentration of energy in tissue mobilized or accreted (MJ/kg DM): $4.972 + (0.3274 \times \text{BW})$ (AFRC, 1998)
- ME_m — ME requirement for maintenance and stall or pen activity (MJ), based on average BW during the experiment: 0.473 MJ/kg $BW^{0.75}$ (Luo et al., 2004a)
- ME_{ft} — ME from mobilized tissue used for FG (MJ): TGN × TEC
- ME_{tg} — ME used for tissue gain (MJ): TGP × 37.2 MJ/kg (Luo et al., 2004a)
- ME_{fgd} — dietary ME used for FG (MJ): $(\text{FG} \times 157\ \text{MJ/kg}) - ME_{ft}$ (Luo et al., 2004a)
- ME_{tot} — total ME metabolized (MJ): $ME_m + ME_{ft} + ME_{tg} + ME_{fgd}$

Table 2
Mean, S.E., minimum and maximum values in the database used for prediction of feed intake by Angora goats[a]

Item	Mean	S.E.	Minimum	Maximum
BW (kg)	29.7	0.98	18.2	45.7
DM intake (kg/day)	0.93	0.028	0.67	1.46
DM intake (% BW)	3.24	0.097	1.99	4.99
Tissue gain (g/day)	46	5.3	−27	139
Clean fiber gain (g/day)	14	0.4	6	24
Dietary ME (MJ/kg DM)	9.8	0.08	8.6	11.0
ME intake (MJ/day)	9.1	0.27	6.8	14.0

[a] $n = 54$.

ME_mPR — ME_m as a proportion of ME_{tot}: ME_m/ME_{tot}
$ME_{tg}PR$ — ME_{tg} as a proportion of ME_{tot}: ME_{tg}/ME_{tot}
$ME_{ft}PR$ — ME_{ft} as a proportion of ME_{tot}: ME_{ft}/ME_{tot}
$ME_{fgd}PR$ — ME_{fgd} as a proportion of ME_{tot}: ME_{fgd}/ME_{tot}
k — assumed constant overall efficiency of ME utilization: $(ME_mPR \times k_m) + (ME_{tg}PR \times k_{tg}) + (ME_{fgd}PR \times k_{fg}) + (ME_{ft}PR \times k_{fg})$; mean k was then used in the following equation to derive ME_{Ptot} (MJ): $ME_{Ptot} = ((ME_m \times k_m) + (ME_{tg} \times k_{tg}) + (ME_{fgd} \times k_{fg}) + (ME_{fgd} \times k_{ft}))/k$

MEI_P and DMI_P were calculated as noted for lactating goats. Because of the relatively small size of the database, no observations were removed, and the database was not split as for lactating goats. The ME_m determined by Luo et al. (2004a) was with mature goats. However, use of a value 5% greater for growing goats, as suggested by Luo et al. (2004a), did not improve fit of our prediction. DMI also was regressed against BW, TG, FG and MEC by multiple regression. Dietary CP concentration (PTCP; mean, S.E., minimum and maximum = 13.2, 0.360, 9.4 and 18.9%, respectively) was included in the multiple regression equation, having a greater effect than the ratio of PTCP:MEC. Likewise, to improve prediction by the efficiency approach, DMI_P was adjusted for PTCP (DMI_{AP}) by regressing DMI against DMI_P and PTCP. Age (less versus greater than 1.5 years of age at the start of the study) was included in the multiple regression model and in the regression of DMI against DMI_{AP} with the efficiency approach, but did not have a significant effect ($P > 0.10$); thus, it was dropped. Other variables used in equations with other databases did not have significant effects with this database ($P > 0.10$). As before, regressions were conducted with REG and GLM procedures of SAS (1990).

2.3. Growing goats

Because the ratio of ADG:BW was used to address potential differences in TEC, separate databases for goats less and greater than 1.5 years of age were used for growing goats (other than Angora; Table 3). Variables employed to predict feed intake were mean BW (kg), biotype (meat, 50% or more Boer; dairy; indigenous, not meat, dairy or Angora), ADGP (kg), ADGN (kg) and MEC (MJ/kg DM). Observations were primarily those of Luo et al. (2004b) with means removed where intake did not appear to be ad libitum. The database included 63 reports and 282 treatment mean. Assumptions were as follows:

k_m — efficiency of ME utilization for maintenance: $0.503 + (0.019 \times MEC)$ (AFRC, 1998)
k_g — efficiency of ME use for tissue gain: $0.006 + (0.0423 \times MEC)$ (AFRC, 1998; mixed, unpelleted diet)
k_t — efficiency of use of mobilized tissue energy for maintenance: k_m
TEC — concentration of energy in mobilized tissue: 23.9 MJ/kg (AFRC, 1998)
ME_mREQ — ME requirement for maintenance and stall or pen activity: 0.489, 0.580 and 0.489 MJ/kg $BW^{0.75}$ for meat, dairy and indigenous goats, respectively (Luo et al., 2004b)
ME_m — ME used for maintenance and pen or stall activity (MJ), based on average BW during the experiment: $ME_mREQ - ME_t$
ME_t — ME from mobilized tissue used for maintenance (MJ): ADGN × TEC
ME_g — ME used for tissue gain (MJ): 23.1, 23.1 and 19.8 MJ/kg for meat, dairy and indigenous goats, respectively (Luo et al., 2004b)
ME_{tot} — total ME metabolized (MJ): $ME_m + ME_t + ME_g$
ME_mPR — ME_m as a proportion of ME_{tot}: ME_m/ME_{tot}
ME_tPR — ME_t as a proportion of ME_{tot}: ME_t/ME_{tot}
ME_gPR — ME_g as a proportion of ME_{tot}: ME_g/ME_{tot}
k — assumed constant overall efficiency of ME utilization: $(ME_mPR \times k_m) + (ME_gPR \times k_g) + (ME_tPR \times k_t)$; mean k was then used in the following equation

Table 3
Mean, S.E., minimum and maximum values in development and evaluation data sets used for prediction of feed intake by growing goats[a]

Item	Development data set				Evaluation data set			
	Mean	S.E.	Minimum	Maximum	Mean	S.E.	Minimum	Maximum
BW (kg)	20.8	0.71	6.4	68.0	21.8	0.83	8.4	43.6
DM intake (kg/day)	0.69	0.24	0.19	1.93	0.72	0.033	0.21	1.65
DM intake (% BW)	3.33	0.044	1.51	4.98	3.32	0.077	1.77	4.53
ADG (g/day)	85	4.8	−107	294	120	9.2	−4	326
ADG:BW (g/kg)	4.1	0.18	−4.0	11.2	5.1	0.33	−0.5	12.4
Dietary ME (MJ/kg DM)	10.2	0.09	7.6	13.8	10.5	0.20	7.0	13.5
ME intake (MJ/day)	7.0	0.26	2.0	17.6	7.7	0.39	1.99	15.1

[a] $n = 192$ and 90 for development and evaluation data sets, respectively.

to predict ME_{Ptot} (MJ): $ME_{Ptot} = ((ME_m \times k_m) + (ME_g \times k_g) + (ME_t \times k_t))/k$

Additional procedures were similar to those described for lactating goats. Observations with residuals greater than 2 × RMSE were removed (16 observations). PTCP and biotype did not have significant effects ($P > 0.10$) when included in regressions of DMI against DMI_P or DMI_{AP} or with multiple regression. The ratio of ADG:BW (ADGBW) and of ADG:metabolic body size (ADGMBW; kg:kg $BW^{0.75}$) and the square of ADGMBW ($ADGMBW^2$) had significant effects ($P < 0.05$) when included in a regression of DMI against P-DMI and, thus, were included in the regression of DMI against DMI_P to derive DMI_{AP}. The same variables were tested for use with multiple regression, but only ADGBW had a significant effect ($P < 0.05$).

After final regressions with the entire database, data sets were constructed randomly by report for equation development and evaluation (192 and 90 observations, respectively). Observations with residuals greater than 2 × RMSE determined with the whole database were excluded from the development data set. The evaluation data set, however, included all observations regardless of size of the residual. Mean k, ADGBW, ADGMBW and $ADGMBW^2$ determined with the development data set were then used to determine DMI_P and DMI_{AP} with the evaluation data set, with regression of DMI against DMI_P and DMI_{AP}. In addition, multiple regressions of DMI against BW, ADG, MEC, ADGBW, ADGMBW and $ADGMBW^2$ were conducted, with inclusion in the final multiple regression (REG and GLM procedures of SAS (1990)) of only those variables with significant effects ($P < 0.05$) (Table 3).

2.4. Mature goats

Variables used to predict feed intake by mature, nonlactating goats (other than Angora) were mean BW (kg), ADGN (kg/day), ADGP (kg/day), MEC (MJ/kg DM) and dietary CP concentration (% DM). Observations were from the report of Luo et al. (2004a), but values from reports where intake did not appear to be ad libitum were excluded. Data of lactating and Angora goats were not included, resulting in a database of 25 reports and 99 treatment means, summarized in Table 4. Assumptions were as follows:

- k_m: efficiency of ME utilization for maintenance: $0.503 + (0.019 \times MEC)$ (AFRC, 1998)
- k_g: efficiency of ME use for tissue gain: $0.006 + (0.0423 \times MEC)$ (AFRC, 1998; mixed, unpelleted diet)
- k_t: efficiency of use of mobilized tissue energy for maintenance: k_m
- TEC: concentration of energy in tissue mobilized or accreted: (MJ/kg DM) 23.9 MJ/kg (INRA, 1988)
- ME_mREQ: ME requirement for maintenance and stall or pen activity: 0.462 MJ/kg $BW^{0.75}$ (Luo et al., 2004a)
- ME_t: ME from mobilized tissue used for maintenance (MJ): TGN × TEC
- ME_m: ME used for maintenance and stall or pen activity (MJ), based on average BW during the experiment: $ME_m REQ - ME_t$

ME_{tg} ME used for tissue gain (MJ): ADG × 28.5 MJ/kg (Luo et al., 2004b)
ME_{tot} total ME metabolized (MJ): $ME_m + ME_t + ME_g$
ME_mPR ME_m as a proportion of ME_{tot}: ME_m/ME_{tot}
ME_gPR ME_g as a proportion of ME_{tot}: ME_g/ME_{tot}
ME_tPR ME_t as a proportion of ME_{tot}: ME_t/ME_{tot}
k assumed constant overall efficiency of ME utilization: $(ME_mPR \times k_m) + (ME_tPR \times k_t) + (ME_gPR \times k_g)$; mean k was then used in the following equation to derive ME_{Ptot} (MJ): $ME_{Ptot} = ((ME_m \times k_m) + (ME_t \times k_t) + (ME_g \times k_g))/k$

MEI_P and DMI_P were calculated as noted previously.

Because of the relatively small size of this database, no observations were excluded and the database was not split as was done for lactating and growing goats. DMI also was regressed against BW, ADG and MEC with multiple regression. With the efficiency approach, PTCP, ADGBW and ADGMBW had significant effects ($P < 0.05$) and increased explained variability when included in the regression with DMI_P to determine DMI_{AP}; effects of $ADGBW^2$ and $ADGMBW^2$ were not significant ($P > 0.10$). The same variables were tested for use with multiple regression, but only PTCP and ADGBW had significant ($P < 0.05$) effect and were included in the final multiple regression equation. Biotype dummy variables did not have a significant effect ($P > 0.10$) when included in regressions of DMI against DMI_P. In addition to use of efficiency and multiple regression approaches, the equation of AFRC (1998) based on INRA (1988) was tested: DMI = 0.522 + (0.0135 × BW). Regressions were conducted with REG and GLM procedures of SAS (1990).

Table 4
Mean, S.E., minimum and maximum values in the database used for prediction of feed intake by mature, nonlactating goats[a]

Item	Mean	S.E.	Minimum	Maximum
BW (kg)	30.1	1.37	7.9	66.0
DM intake (kg/day)	0.78	0.039	0.13	2.13
DM intake (% BW)	2.64	0.072	1.28	4.57
ADG (g/day)	33	6.0	−275	243
Dietary ME (MJ/kg DM)	9.1	0.152	3.91	12.29
ME intake (MJ/day)	7.1	0.367	1.3	18.2

[a] $n = 99$.

3. Results

3.1. Lactating goats

3.1.1. Initial regressions

The initial estimate of k with the whole database was 0.671 (S.E. = 0.00114) for Method 1 and 0.653 (S.E. = 0.00132) for Method 2. Corresponding equations for regressions of DMI against DMI_P are L1 and L2 (Table 5). Intercepts differed from 0 and slopes differed from 1 ($P < 0.05$). The multiple regression equation is L3, and the equation for the regression with the AFRC (1998) equation is L4.

3.1.2. Reduced database

There were 12 and 16 observations with residuals greater than 2 × RMSE for Methods 1 and 2, respectively. Removal of these observations resulted in k of 0.671 (S.E. = 0.00112) and 0.654 (S.E. = 0.00138) for Methods 1 and 2, respectively. This decreased intercepts and increased slopes (equations L5 and L6, respectively; Table 5). The multiple regression equation with the Method 2 database is L7, and the equation for the regression with the AFRC (1998) equation and Method 2 database is L8.

There were 24 and 30 observations with Methods 1 and 2, respectively, with residuals greater than 1.5 × RMSE. Ten of these observations were from three reports that did not consist of any other observations. The other 14 or 20 observations constituted one or two of the observations in the reports, which consisted of other observations that remained in the database. Each report entailed measures in early lactation; however, there were many other early lactation observations that remained in the database. Studies included in the database were presumed to have ad libitum intake, but in some cases it was difficult to be certain based on procedural descriptions (e.g., “goats were fed according to assumed requirements”). Hence, removing outlying observations from the development data set seems appropriate.

Table 5
Equations for prediction of feed intake by goats

Production state or type and equation number	n	R^2	RMSE[a]	Equation[b]
Lactating goats				
L1	221	0.75	0.2943	Method 1, DMI = 0.2804 (S.E. = 0.07479) + (0.8536 (S.E. = 0.033344) × DMI_P)
L2	221	0.75	0.2915	Method 2, DMI = 0.2458 (S.E. = 0.07515) + (0.8401 (S.E. = 0.03250) × DMI_P)
L3	221	0.78	0.2800	DMI = 1.1853 (S.E. = 0.19437) + (0.0117 (S.E. = 0.00216) × BW) + (0.4343 (S.E. = 0.02200) × FCM) − (0.0720 (S.E. = 0.01881) × MEC) + (1.3565 (S.E. = 0.22729) × ADG)
L4	221	0.71	0.3164	DMI = 0.0929 (S.E. = 0.09032) + (1.0240 (S.E. = 0.04431) × DMI_P)
L5	209	0.79	0.2511	Method 1, DMI = 0.1647 (S.E. = 0.07195) + (0.9202 (S.E. = 0.03295) × DMI_P)
L6	205	0.79	0.2446	Method 2, DMI = 0.0973 (S.E. = 0.07429) + (0.9300 (S.E. = 0.03324) × DMI_P)
L7	205	0.81	0.2388	DMI = 2.0801 (S.E. = 0.20090) + (0.0115 (S.E. = 0.00187) × BW) + (0.4621 (S.E. = 0.02097) × FCM) − (0.1590 (S.E. = 0.01934) × MEC) + (1.5823 (S.E. = 0.21315) × ADG)
L8	205	0.68	0.3061	DMI = 0.1936 (S.E. = 0.09572) + (0.9814 (S.E. = 0.04753) × DMI_P)
L9	197	0.83	0.2252	Method 1, DMI = 0.0916 (S.E. = 0.06799) + (0.9570 (S.E. = 0.03145) × DMI_P)
L10	191	0.83	0.2206	Method 2, DMI = 0.0560 (S.E. = 0.06829) + (0.9492 (S.E. = 0.03074) × DMI_P)
L11	191	0.84	0.2207	DMI = 2.0423 (S.E. = 0.18713) + (0.0119 (S.E. = 0.00175) × BW) + (0.4641 (S.E. = 0.01963) × FCM) − (0.1583 (S.E. = 0.01813) × MEC) + (1.6866 (S.E. = 0.22453) × ADG)
L12	191	0.71	0.2919	DMI = 0.1755 (S.E. = 0.09219) + (0.9911 (S.E. = 0.04603) × DMI_P)
L13	197	0.83	0.2234	Method 1, DMI = 0.1295 (S.E. = 0.07004) + (0.9417 (S.E. = 0.03214) × DMI_P) − (0.1217 (S.E. = 0.06036) × ADGFCM)
L14	191	0.84	0.2187	Method 2, DMI = 0.0964 (S.E. = 0.07039) + (0.9334 (S.E. = 0.03140) × DMI_P) − (0.1237 (S.E. = 0.059236) × ADGFCM)
L15	197	0.84	0.2228	Method 1, DMI = 0.0000 (S.E. = 0.07005) + (1.0000 (S.E. = 0.03248) × DMI_{AP})
L16	191	0.84	0.2181	Method 2, DMI = 0.0000 (S.E. = 0.06911) + (1.000 (S.E. = 0.03194) × DMI_{AP})
L17	78	0.85	0.2041	Method 1, DMI = 0.0993 (S.E. = 0.10522) + (0.9232 (S.E. = 0.04495) × DMI_P)
L18	78	0.85	0.2024	Method 2, DMI = 0.0444 (S.E. = 0.10675) + (0.9140 (S.E. = 0.04405) × DMI_P)
L19	78	0.85	0.2053	Method 1, DMI = −0.0848 (S.E. = 0.11477) + (0.9925 (S.E. = 0.04866) × DMI_{AP})
L20	78	0.85	0.2035	Method 2, DMI = −0.1183 (S.E. = 0.11518) + (0.9932 (S.E. = 0.04819) × DMI_{AP})
L21	120	0.83	0.2262	DMI = 2.3971 (S.E. = 0.27914) + (0.0092 (S.E. = 0.00251) × BW) + (0.4912 (S.E. = 0.02904) × FCM) − (0.1819 (S.E. = 0.02644) × MEC) + (1.4896 (S.E. = 0.30890) × ADG)

Table 5 (*Continued*)

Production state or type and equation number	n	R^2	RMSE[a]	Equation[b]
L22	78	0.79	0.2388	$DMI = 0.1257$ (S.E. $= 0.12566$) $+ (0.8986$ (S.E. $= 0.05297) \times DMI_P)$
L23	78	0.71	0.2817	$DMI = -0.2304$ (S.E. $= 0.1819$) $+ (1.1229$ (S.E. $= 0.0825) \times DMI_P)$
L24	196	0.87	0.2023	$DMI = 1.7317$ (S.E. $= 0.18445$) $+ (0.0095$ (S.E. $= 0.00160) \times BW) + (0.4445$ (S.E. $= 0.01674) \times FCM) - (0.1152$ (S.E. $= 0.01701) \times MEC) + (1.3075$ (S.E. $= 0.17309) \times ADG)$
L25	78	0.79	0.2394	$DMI = -0.0768$ (S.E. $= 0.13782$) $+ (1.0057$ (S.E. $= 0.05949) \times DMI_P)$
L26	78	0.82	0.2221	$DMI = 0.3334$ (S.E. $= 0.10406$) $+ (0.8122$ (S.E. $= 0.04376) \times DMI_P)$
Angora goats				
A1	54	0.60	0.1321	$DMI = -0.0176$ (S.E. $= 0.10949$) $+ (0.9414$ (S.E. $= 0.10689) \times DMI_P)$
A2	54	0.65	0.1239	$DMI = -0.1607$ (S.E. $= 0.11430$) $+ (0.8227$ (S.E. $= 0.10851) \times DMI_P) + (0.0199 \times PTCP)$
A3	54	0.65	0.1227	$DMI = -0.0001$ (S.E. $= 0.09569$) $+ (0.9996$ (S.E. $= 0.10083) \times DMI_{AP})$
A4	54	0.62	0.1318	$DMI = 0.2131$ (S.E. $= 0.37141$) $+ (0.0194$ (S.E. $= 0.00267) \times BW) + (2.3658$ (S.E. $= 0.53307) \times TG) + (16.1250$ (S.E. $= 5.86352) \times FG) - (0.0191$ (S.E. $= 0.03453) \times MEC)$
A5	54	0.66	0.1266	$DMI = 0.2884$ (S.E. $= 0.35815$) $+ (0.0176$ (S.E. $= 0.00268) \times BW) + (2.06555$ (S.E. $= 0.52865) \times TG) + (10.29458$ (S.E. $= 6.18810) \times FG) - (0.03565$ (S.E. $= 0.03394) \times MEC) + (0.0177$ (S.E. $= 0.00781) \times PTCP)$
A6	54	0.66	0.1216	$DMI = -0.0004$ (S.E. $= 0.0944$) $+ (1.0007$ (S.E. $= 0.0995) \times DMI_P)$
A7	54	0.46	0.1538	$DMI = 0.2899$ (S.E. $= 0.09965$) $+ (0.6365$ (S.E. $= 0.09628) \times DMI_P)$
Growing goats				
G1	282	0.85	0.1276	$DMI = -0.0854$ (S.E. $= 0.02110$) $+ (1.1381$ (S.E. $= 0.02855) \times DMI_P)$
G2	282	0.85	0.1266	$DMI = 0.4585$ (S.E. $= 0.06092$) $+ (0.0229$ (S.E. $= 0.00107) \times BW) + (1.9349$ (S.E. $= 0.13425) \times ADG) - (0.0417$ (S.E. $= 0.00598) \times MEC)$
G3	266	0.86	0.1065	$DMI = -0.0464$ (S.E. $= 0.01843$) $+ (1.0579$ (S.E. $= 0.02583) \times DMI_P)$
G4	266	0.87	0.1044	$DMI = 0.4605$ (S.E. $= 0.05312$) $+ (0.0203$ (S.E. $= 0.00096) \times BW) + (1.9815$ (S.E. $= 0.12854) \times ADG) - (0.0387$ (S.E. $= 0.00526) \times MEC)$
G5	266	0.88	0.1030	$DMI = -0.0047$ (S.E. $= 0.03072$) $+ (0.9637$ (S.E. $= 0.04928) \times DMI_P) - (70.27$ (S.E. $= 23.534) \times ADGBW) + (38.71$ (S.E. $= 12.224) \times ADGMBW) - (243.4$ (S.E. $= 121.73) \times ADGMBW^2)$
G6	266	0.88	0.1024	$DMI = 0.0001$ (S.E. $= 0.01634$) $+ (1.0000$ (S.E. $= 0.02280) \times DMI_{AP})$

Table 5 (*Continued*)

Production state or type and equation number	n	R^2	RMSE[a]	Equation[b]
G7	266	0.87	0.1032	DMI = 0.5029 (S.E. = 0.05477) + (0.0168 (S.E. = 0.00161) × BW) + (2.8545 (S.E. = 0.34922) × ADG) − (20.5651 (S.E. = 7.6629) × ADGBW) − (0.0350 (S.E. = 0.00531) × MEC)
G8	90	0.83	0.1248	DMI = −0.0874 (S.E. = 0.04089) + (1.1005 (S.E. = 0.05260) × DMI_P)
G9	90	0.84	0.1236	DMI = −0.0390 (S.E. = 0.03825) + (1.0096 (S.E. = 0.04768) × DMI_{AP})
G10	90	0.82	0.1288	DMI = −0.0092 (S.E. = 0.03890) + (0.9709 (S.E. = 0.04822) × DMI_P)
G11	265	0.90	0.0995	DMI = 0.4413 (S.E. = 0.05110) + (0.02140 (S.E. = 0.00092) × BW) + (2.0780 (S.E. = 0.11914) × ADG) − (0.0394 (S.E. = 0.00489) × MEC)
G12	90	0.83	0.1278	DMI = 0.0049 (S.E. = 0.03778) + (0.9570 (S.E. = 0.04706) × DMI_P)
G13	90	0.83	0.1270	DMI = −0.0051 (S.E. = 0.03967) + (0.9689 (S.E. = 0.04730) × DMI_P)
Mature goats				
M1	99	0.67	0.2200	DMI = −0.0601 (S.E. = 0.06327) + (1.0796 (S.E. = 0.07620) × DMI_P)
M2	99	0.85	0.1537	DMI = −0.1241 (S.E. = 0.07374) + (0.7915 (S.E. = 0.06911) × DMI_P) + (0.0214 (S.E. = 0.00381) × PTCP) − (535.2 (S.E. = 66.35) × ADGBW) + (247.3 (S.E. = 29.53) × ADGMBW)
M3	99	0.85	0.1513	DMI = −0.0005 (S.E. = 0.03709) + (0.9999 (S.E. = 0.04335) × DMI_{AP})
M4	99	0.77	0.1876	DMI = 0.3544 (S.E. = 0.12541) + (0.0217 (S.E. = 0.00141) × BW) + (2.0562 (S.E. = 0.34046) × ADG) − (0.0324 (S.E. = 0.01318) × MEC)
M5	99	0.82	0.1654	DMI = 0.3494 (S.E. = 0.12318) + (0.0165 (S.E. = 0.00190) × BW) + (4.8260 (S.E. = 0.77739) × ADG) − (101.7 (S.E. = 23.55) × ADGBW) − (0.0387 (S.E. = 0.01173) × MEC) + (0.0194 (S.E. = 0.00417) × PTCP)
M6	99	0.82	0.1620	DMI = −0.0007 (S.E. = 0.04016) + (1.0001 (S.E. = 0.04704) × DMI_P)
M7	99	0.68	0.2187	DMI = −0.8110 (S.E. = 0.11351) + (1.71440 (S.E. = 0.12001) × DMI_P)
M8	99	0.36	0.3088	DMI = 0.3235 (S.E. = 0.06939) + (0.5590 (S.E. = 0.07604) × DMI_P)

[a] DMI: DM intake (kg); BW: body weight (kg); FCM = 4% fat-corrected milk (kg); MEC: dietary concentration of ME (MJ/kg DM); ADG: average daily gain (kg); DMI_P: predicted DMI; ADGFCM: ratio of ADG:FCM (kg/kg); PTCP: dietary concentration of CP (% DM); DMI_{AP}: adjusted prediction of DMI; TG: tissue gain (kg); FG: clean mohair fiber gain (kg); ADGBW ratio of ADG:BW (kg/kg); ADGMBW: ratio of ADG:$BW^{0.75}$ (kg/$kg^{0.75}$); $ADBMBW^2$: square of the ratio of ADG:$BW^{0.75}$ ((kg/$kg^{0.75})^2$).

[b] Root mean square error.

Using databases of observations with residual errors greater than 1.5 × RMSE excluded, k was 0.671 (S.E. = 0.00113) and 0.653 (S.E. = 0.00139) for Methods 1 and 2, respectively. Use of these k resulted in equations L9 and L10 (Table 5). Intercepts were not different from 0 and slopes did not differ from 1 ($P > 0.10$). The multiple regression equation with the Method 2 database is L11, and the equation for the regression with the AFRC (1998) equation is L12. Equations for adjusting DMI_P for ADGFCM are L13 and L14, and equations for regressions of DMI against DMI_{AP} are L15 and L16.

3.1.3. Evaluation data set

Mean k determined with development data sets was 0.671 (S.E. = 0.00143) and 0.654 (S.E. = 0.00183) for Methods 1 and 2, respectively. When applied to the evaluation data set, regressions of DMI against predicted DMI_P and DMI_{AP} (L17, L18, L19 and L20; Table 5) resulted in intercepts not different from 0 ($P > 0.10$) and slopes not different from 1 ($P > 0.05$ and 0.10 for DMI_P and DMI_{AP}, respectively).

The multiple regression equation derived with the Method 2 development data set is L21 (Table 5). The equation for the regression of DMI of the evaluation data set against DMI_P predicted from the multiple regression equation derived with the Method 2 development data set is L22. The slope differed from 0 ($P < 0.05$). The equation for the regression of DMI against DMI_P predicted from the AFRC (1998) equation is L23; the intercept was not different from 0 and the slope was not different from 1 ($P > 0.10$).

As a means of further evaluating prediction approaches, relative acceptability limits were employed with the evaluation data set. Predictions within 10 and 20% of the mean were classified as acceptable and marginally acceptable, respectively, and predictions differing by over 20% of the mean were categorized as unacceptable. For Method 1, 74.4, 21.8 and 3.8% of DMI_P, and 66.7, 26.9 and 6.4% of DMI_{AP} were acceptable, marginally acceptable and unacceptable, respectively. For Method 2, 64.1, 26.9 and 9.0% of DMI_P, and 67.9, 25.6 and 6.4% of DMI_{AP} were acceptable, marginally acceptable and unacceptable, respectively. For multiple regression, 78.2, 11.5 and 10.3% were acceptable, marginally acceptable and unacceptable, respectively. For the equation of AFRC (1998), 60.3, 33.1 and 6.4% were acceptable, marginally acceptable and unacceptable, respectively.

Because of the possibility that the comparison of methods of prediction with the evaluation data set might be influenced by removal of observations in the development data set based on RMSE with Method 2, the same procedures were employed for predictions based on multiple regression. With removal of observations with residuals greater than 1.5 × RMSE from the database based on multiple regression, the resulting equation is L24 (Table 5). Coefficients from the comparable equation from a reduced development data set were used to determine DMI_P for the evaluation data set, resulting in equation L25. Hence, the removal of observations from the data set did affect accuracy and bias of prediction by multiple regression. For field application of the multiple regression approach, use of equation L24 would be recommended. To evaluate the impact of use of the assumption of constant k, MEI and DMI were predicted from the sum of ME_m, ME_g and ME_{lt}, with the equation for the regression of DMI against DMI_P being L26.

3.2. Angora goats

Mean k was 0.525 (S.E. = 0.00526). The equation for the regression of observed against predicted DMI is A1 (Table 5). The equation for the regression of DMI against DMI_P and PTCP is A2, and the equation for the regression of DMI against DMI_{AP} is A3. The first multiple regression equation is A4, the multiple regression equation including PTCP is A5 and the equation for the regression of DMI predicted from the multiple regression equation with inclusion of PTCP is A6.

Relative acceptability limits were employed as described previously for lactating goats. For the k approach and adjustment for PTCP, 50.0, 42.6 and 7.4% of DMI_P and DMI_{AP} were acceptable, marginally acceptable and unacceptable, respectively. For multiple regression with inclusion of PTCP, 59.3, 31.5 and 9.3% of predictions were acceptable, marginally acceptable and unacceptable, respectively. To evaluate the impact of use of the assumption of constant k, MEI and DMI were predicted from the sum of ME_m, ME_{tg} and ME_{fgd}, with the equation for the regression of DMI against DMI_P being A7.

3.3. Growing goats

3.3.1. Initial regressions

The initial estimate of k with the whole database was 0.633 (S.E. = 0.0020). The corresponding equation for the regression of DMI against DMI_P is G1 (Table 5). The intercept differed from 0 and the slope differed from 1 ($P < 0.05$). The multiple regression equation is G2.

3.3.2. Reduced database

There were 16 observations with residuals greater than $2 \times$ RMSE, without any apparent distinguishable characteristics. In most reports previous nutritional plane was not fully described. It is possible that differences in previous nutritional plane or capacity for compensatory growth, with potential impact on feed intake, affected how well observations fit regression lines. Removal of these observations resulted in a k of 0.634 (S.E. = 0.0020), with an increase in the intercept and decrease in the slope (equation G3; Table 5). The slope remained different from 0 and the intercept was also different from 1 ($P < 0.05$). The multiple regression equation is G4.

As noted earlier, DMI was regressed against DMI_P, ADGBW, ADGMBW and $ADGMBW^2$, resulting in equation G5, with the equation for the regression of DMI against DMI_{AP} being G6 (Table 5). Likewise, ADGBW had a significant effect ($P < 0.05$) when included in the multiple regression equation G7.

3.3.3. Evaluation data set

Mean k determined with development data set was 0.637 (S.E. = 0.00223). When applied to the evaluation data set, regression of DMI against DMI_P resulted in an intercept different from 0 ($P < 0.05$) and a slope not different from 1 ($P > 0.10$; equation G8, Table 5). However, with regression against DMI_{AP} determined from regression coefficients estimated with the development data set with the same independent variables as used previously with the entire database, the intercept was not different from 0 ($P > 0.10$) and the slope was not different from 1 ($P > 0.10$; equation G9). The equation for the regression of DMI against DMI_P from the multiple regression equation derived with the development data set is G10; the intercept was not different from 0 and the slope was not different from 1 ($P > 0.10$).

As a means to evaluate prediction approaches further, relative acceptability limits again were employed with the evaluation data set. With the efficiency approach, 47.2, 31.5 and 21.6% for DMI_P and 42.7, 31.5 and 25.8% of observations for DMI_{AP} were acceptable, marginally acceptable and unacceptable, respectively. For multiple regression, 50.6, 23.6 and 25.8% were acceptable, marginally acceptable and unacceptable, respectively.

Because the comparison of methods of prediction with the evaluation data set might be influenced by removal of observations in the development data set based on RMSE with the efficiency approach, the same procedures were employed for predictions based on multiple regression. The multiple regression equation with the reduced database is G11 (Table 5). Effects of other variables when included in the model were not significant ($P > 0.10$). When coefficients from a comparable equation derived from a reduced development data set were used to derive DMI_P from the evaluation data set, the intercept of the equation (G12) was not different from 0 ($P > 0.10$) and the slope was not different from 1 ($P > 0.10$). Because removal of outlying observations did not greatly influence prediction, use of multiple regression to predict feed intake could be with coefficients of either equation G7 or G11.

To evaluate the impact of use of the assumption of constant k, MEI and DMI were predicted from the sum of ME_m and ME_g. In contrast to lactating, Angora and mature goat databases, for growing goats this approach resulted in prediction as accurate as that with the efficiency approach (equation G13; Table 5).

3.4. Mature goats

Mean k was 0.632 (S.E. = 0.00448). The equation for the regression of DMI against DMI_P is M1 (Table 5). The final adjustment equation is M2, and the equation for the regression of DMI against DMI_{AP} is M3.

The first multiple regression equation is M4 (Table 5). The final multiple regression equation including other variables is M5. The equation for the regression of DMI predicted from the final multiple regression equation is M6; the intercept was not different from 0 ($P > 0.10$) and the slope was not different from 1 ($P > 0.10$). The equation for the regression of DMI against DMI_P with the AFRC (1998) equation is M7; the intercept was not different from 0 ($P > 0.10$) and the slope was different ($P < 0.05$) from 1.

Relative acceptability limits were employed as described earlier. For the efficiency approach without adjustment, 27.3, 28.3 and 44.4% of DMI_P were acceptable, marginally acceptable and unacceptable, respectively. For the k approach with adjustment, there were 42.4, 35.4 and 22.2% of observations that were acceptable, marginally acceptable and unacceptable, respectively. For multiple regression with inclusion of PTCP, 36.3, 44.4 and 19.1% of predictions were acceptable, marginally acceptable and unacceptable, respectively. For the AFRC (1998) equation, 19.2, 19.2 and 61.6% of predictions were acceptable, marginally acceptable and unacceptable, respectively. To evaluate the impact of use of the assumption of constant k, MEI and DMI were predicted from the sum of ME_m and ME_g; the equation for the regression of DMI against DMI_P is M8.

4. Discussion

4.1. Approaches

Although multiple approaches can be used to predict feed intake by goats and other ruminants, none are considered "most appropriate" by a majority of researchers. One empirical approach is to use a large number of inputs to thoroughly describe feed and animal conditions, but without specifying level of production (e.g., FCM, TG or ADG). This method allows prediction of production for a given diet and animal. However, some "without production data" approaches can require a large number of inputs, some which may not be known, necessitating uncertain assumptions or gross categorizations. Also, for a study such as the present one, use of a method relying on many diet and animal descriptors would have limited numbers of observations and potential users. With the efficiency and multiple regression approaches we used, the number of input variables is relatively small, i.e., BW, MEC, ADG and FCM for lactating goats, BW, MEC, TG and FG for Angora goats, BW, MEC and ADG for growing and mature goats and PTCP for Angora and mature goats.

Though the objective of this investigation was not the study of factors controlling voluntary intake by goats, but rather to develop useful equations for prediction, these findings suggest that the assumption of constant overall efficiency of ME utilization for feed intake prediction has utility as proposed by Tolkamp and Ketelaars (1994). That the sum of ME needs for different functions resulted in less accurate prediction than the efficiency approach with lactating, Angora and mature goats may be because the constant k assumption compensated or corrected for inaccuracies in assumptions of constant efficiencies of ME use for the various functions as well as ME requirements. Because the efficiency approach with adjustments was as effective as multiple regression with independent variables of BW, FCM, ADG and MEC for predicting feed intake, factors affecting feed intake were being considered adequately. Over 80% of variation was explained by efficiency and multiple regression approaches for lactating, growing and mature goats, and over 60% of the variation was explained for Angoras.

Additional factors that contribute to unexplained variability may include ones not provided in most reports. For example, parity of lactating goats may influence energy requirements or efficiency of ME use; although, use of ADG and (or) BW and BW^2 would at least partially consider this effect. Likewise, ME_m was assumed to be constant throughout a lactation cycle. However, this concern may relate primarily to the mode of accounting, in that potential changes in ME_m with advancing stage of lactation and the associated impact on predicted feed intake might be at least partly addressed by the FCM input, with the end-product effect a function of differences between k_m and k_{ld}. In addition, as noted below ADGFCM was used to adjust on the premise of a relationship with ME_m. Assumptions of TEC, which were considered in this study by adjusting with ADGBW, deserve future research attention. Similarly, the potential effect on predicted intake of the assumption of constant ME_m regardless of previous nutritional plane was addressed by adjusting for ADGMBW and $ADGMBW^2$. Acclimatization and characteristics of the diet that potentially affect efficiency of ME utilization that are not fully described by MEC also were not included in this study.

4.2. Assumptions

We attempted to use consistent and appropriate assumptions and employ ones from the recent thorough review of goat nutrient requirements of AFRC (1998). However, we also tested various alternatives. For example, since both growing and mature goats were part of the Angora database, the composition of gain equation used by AFRC (1998), which depends on BW, was used instead of a constant TEC, because use of 23.9 MJ/kg for TEC resulted in less accurate prediction. ME_m and efficiencies of ME utilization determined in studies of Luo et al. (2004a,b) and Nsahlai et al. (2004) were applied since many of the reports in those databases were those of the present study.

One difference in assumptions between lactating and Angora goats, as compared with growing and mature goats, was the fate of mobilized tissue energy. For lactating and Angora goats, all mobilized tissue energy was assumed to be used for milk or fiber synthesis. Insufficient information is available concerning partitioning of mobilized energy to maintenance versus productive functions. Thus, ME_m was assumed to arise solely from dietary energy, based only on the requirement and $BW^{0.75}$. This may have increased the error in predicting intake of Angora more than of lactating goats because of the greater difference between k_m and k_{fg} versus k_m and k_{ld}. Conversely, for growing and mature goats losing BW, it was assumed that tissue energy was used for maintenance with the same efficiency as energy from the diet.

4.3. Adjustments

Increased prediction accuracy with Angora and mature goats when DMI_P with the efficiency approach was adjusted for PTCP implies that characterization of effects of PTCP on efficiency of ME utilization is needed. Effects of PTCP on k_m and k_{tg} have been observed (Blaxter and Boyne, 1978), but its influence on k_{fg} has not been studied. With the relatively high mean PTCP (13.2%) and minimum and maximum values of 9.4 and 18.9%, respectively, in the Angora database, PTCP should not have affected k_m, which suggests that k_{fg} was influenced. Conversely, with mature goats, the effect of PTCP on intake prediction, with some diets being very low (e.g., minimum of 2.2%), probably involved an influence related to the assumption that k_m varied only with MEC. Because of the nature of the databases, PTCP did not improve intake prediction by lactating or growing goats; hence, accurate field prediction of intake would depend on adequate PTCP for these classes.

Regarding adjustment of DMI_P with the efficiency approach by ADGBW, ADGMBW, $ADGMBW^2$ and ADGFCM, we cannot conclusively identify specific assumptions responsible for their effects on regressions of DMI. Nonetheless, a brief description can be provided for experimental conditions in database reports that could have given rise to these adjustments, production conditions to which adjustments might be particularly useful and possible assumption considerations.

ADGBW was tested because of potential unaccounted effects of TEC on ME_g. The AFRC (1998) equation to predict composition of BW gain, only relying on BW, resulted in less accurate prediction for lactating, growing and mature goats than the constant TEC employed, and inadequate data were available to develop an appropriate method to predict variable TEC. The relationship between ADGBW and TEC is unknown. With other ruminant species such as beef cattle (NRC, 2000), TEC might be expected to increase with increasing ADGBW because of an increasing concentration of fat and decreasing levels of protein and water. However, the negative regression coefficient for ADGBW suggests a negative relationship in the growing and mature goat databases, with high ADG associated with gain of tissue high in protein and water and low in fat compared with low ADGBW. Hence, ME_g in the estimation of MEI_P might have been slightly overestimated for observations with high ADG and underestimated for ones with negative ADGBW.

ADGMBW was tested because of potential unaccounted effects of current and previous nutritional plane on k_m or k_g, which were assumed to vary only with MEC. The positive regression coefficient could indicate that k_m or k_g was greater than assumed when ADGMBW was high, possibly during compensatory growth following a low nutritional plane. Correspondingly, when ADGMBW was low, as for goats previously on a relatively high nutritional plane, k_m may have been less than we assumed. The effect of $ADGMBW^2$ indicates that the adjustment was small when ADGMBW was near 0, with decreases in DMI_P as ADGMBW decreased or increased from 0, reflecting an impact of level of intake relative to maintenance. Perhaps the fact that only the linear effect of ADGMBW was significant for mature goats reflects shorter periods of compensatory growth with decreased ME_m following nutrient restriction, smaller magnitudes of change relative to the assumed ME_m or lower ME_m of mature versus growing goats.

ADGFCM was tested with lactating goats because of potential unaccounted effects of stage of lactation on ME_m, which was assumed constant throughout a lactation cycle. The negative regression coefficient for ADGFCM could be a result of lower ME_m than assumed during BW loss, such as in early lactation. In accordance, in mid- and late-lactation, when BW is gained, ME_m may have been greater than assumed.

The methods used in these studies to predict feed intake are applicable to pen or stall settings; adjustments may be required for use under grazing conditions. It is unclear how such adjustments for multiple regression could be made without further research. However, the efficiency approach could be used with grazing goats, contingent upon knowledge of additional energy expended in activity, which would increase ME_m. Similarly, ME_m for goats acclimated to different temperatures could be used.

4.4. Recommendations

Because the number of observations was greater for the entire database than for the development data sets, and because DMI_{AP} provided unbiased prediction of DMI by lactating and growing goats with evaluation data sets, use of a mean *k* from the reduced databases is preferable. Based on the assumptions outlined above for lactating goats, Methods 1 and 2 for addressing ME_m yielded *k* values of 0.671 and 0.653, respectively; these are recommended, along with adjustment for ADGFCM as applied in equations L13 and L14. For Angora goats, a *k* value of 0.525 with adjustment for PTCP as in equation A2 seem most appropriate. For growing goats, a *k* value of 0.634 with adjustments (i.e., ADGBW, ADGMBW and $ADGMBW^2$) shown in equation G5 are proposed. Lastly, for mature goats, a *k* value of 0.632 with adjustments (i.e., PTCP, ADGBW and ADGMBW) noted in equation M2 are suggested.

5. Summary and conclusions

Using databases of treatment means from the literature, methods to predict feed intake by lactating, Angora, growing and mature goats were developed, based on BW, MEC and PTCP (Angora and mature goats). A factorial approach was used together with a calculated constant overall efficiency of ME utilization based on assumptions of ME requirements and efficiencies of use for maintenance, BW change, change in tissue mass, fiber gain and lactation, along with adjustments based on PTCP and ratios of independent variables being used. Equations were also developed via multiple regression analysis using BW, MEC, production levels and their ratios and PTCP as independent variables. Accuracy of prediction was similar for the two methods. Because of the relatively large number of observations in this study, these methods should be useful for predicting voluntary intake of various diets by a variety of goats in or near thermoneutral conditions and with pen or stall settings. This efficiency approach also should be of value under other settings where maintenance energy requirements are different, as with grazing or acclimatization, with appropriate changes in ME requirements. Further research to determine more accurate values for efficiencies of use of dietary ME for lactation, BW gain, tissue gain and fiber growth and of tissue energy for lactation and fiber growth is desirable, such as characterizing effects of PTCP, TEC and present and subsequent nutritional plane, which could improve prediction accuracy with the efficiency approach.

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Appendix A

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