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Short communication: Prediction of intake in dairy cows under tropical conditions

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ABSTRACT

A meta-analysis was conducted to develop a model for predicting dry matter intake (DMI) in dairy cows under the tropical conditions of Brazil and to assess its adequacy compared with 5 currently available DMI prediction models: Agricultural and Food Research Council (AFRC); National Research Council (NRC); Cornell Net Carbohydrate and Protein System (CNCPS; version 6); and 2 other Brazilian models. The data set was created using 457 observations (n = 1,655 cows) from 100 studies, and it was randomly divided into 2 subsets for statistical analysis. The first subset was used to develop a DMI prediction equation (60 studies; 309 treatment means) and the second subset was used to assess the adequacy of DMI predictive models (40 studies; 148 treatment means). The DMI prediction model proposed in the current study was developed using a nonlinear mixed model analysis after reparameterizing the NRC equation but including study as a random effect in the model. Body weight (mean = 540 ± 57.6 kg), 4% fat-corrected milk (mean = 21.3 ± 7.7 kg/d), and days in milk (mean = 110 ± 62 d) were used as independent variables in the model. The adequacy of the DMI prediction models was evaluated based on coefficient of determination, mean square prediction error (MSPE), root MSPE (RMSPE), and concordance correlation coefficient (CCC). The observed DMI obtained from the data set used to evaluate the prediction models averaged 17.6 ± 3.2 kg/d. The following model was proposed: DMI (kg/d) = $[0.4762\ (\pm 0.0358) \times 4\%$ fat-corrected milk $+ 0.07219\ (\pm 0.00605) \times$ body weight$^{0.75}]$ $\times\ (1 - e^{-0.03202\ (\pm 0.00615)\ \times\ [\text{days in milk}\ +\ 24.9576\ (\pm 5.909)]})$. This model explained 93.0% of the variation in DMI, predicting it with the lowest mean bias (0.11 kg/d) and RMSPE (4.9% of the observed DMI) and the highest precision [correlation coefficient estimate (ρ) = 0.97] and accuracy [bias correction factor (C_b) = 0.99]. The NRC model prediction equation explained 92.0% of the variation in DMI and had the second lowest mean bias (0.42 kg/d) and RMSPE (5.8% of the observed DMI), as well as the second highest precision (ρ = 0.94) and accuracy (C_b = 0.98). The CNCPS and AFRC DMI prediction models explained 93.0 and 85.0% of the variation in DMI but underpredicted DMI by 1.8 and 1.4 kg/d, respectively. These 2 models (CNCPS and AFRC) resulted, respectively, in RMSPE of 11.3 and 10.7% of the observed DMI, with moderate to high precision (ρ = 0.81 and 0.82) and accuracy (C_b = 0.84 and 0.89). The remaining 2 models resulted in the poorest results, underpredicting DMI by 2.3 and 1.9 kg/d, with RMSPE of 22.8 and 14.9% of the observed DMI and moderate to low precision (ρ = 0.49 and 0.76) and accuracy (C_b = 0.81 and 0.86). The new model derived from the current meta-analytical approach provided the best accuracy and precision for predicting DMI in lactating dairy cows under Brazilian conditions.
Key words: meta-analysis, modeling, prediction of feed intake

Short Communication

Accurate prediction of feed intake by dairy cows is essential for optimizing nutrient utilization in dairy diets, which can potentially increase the productive, economic, and environmental performance of dairy systems. Despite the complexity of the mechanisms regulating feed intake, several currently available models [e.g., Agricultural and Food Research Council (AFRC, 1993); NRC, 2001; Freitas et al., 2006; Cornell Net Carbohydrate and Protein System (**CNCPS**, version 6.0; Tylutki et al., 2008); Santos et al., 2009] use empirical approaches to predict DMI with animal-related variables such as BW, milk production and composition, and DIM as fixed effects in the models. It is important to note, however, that application of empirical models is population-dependent, thus restricting their use to specific environmental and geographical conditions.

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Table 1. Selected models for predicting DMI (kg/d) in lactating dairy cows

Model[1]	Equation[2]
NRC (2001)	$DMI = (0.372 \times 4\%\ FCM + 0.0968 \times BW^{0.75}) \times (1 - e^{[-0.192 \times (WOL + 3.67)]})$
CNCPS (Tylutki et al., 2008)	$DMI = (0.0185 \times BW \times 0.95 + 0.305 \times 4\%\ FCM) \times (1 - e^{[-(0.564 - 0.124 \times 2) \times (WOL + 2)]})$
Vadivello and Holmes (1979); AFRC (1993)	$DMI = 0.076 + 0.404 \times CI + 0.013 \times BW - 0.129 \times WOL + 4.12 \times Log_{10}(WOL) + 0.14 \times MY$
Freitas et al. (2006)	$DMI = -100 + 0.116 \times BW + 2.91 \times MY + 22.8 \times MF - 2.6 \times MF^2 - 0.00483 \times BW \times MY$
Santos et al. (2009)	$DMI = (0.6089 \times 4\%\ FCM + 0.0244 \times BW^{0.75}) \times (1 - e^{[-0.2919 \times (DIM + 5.5772)]})$

[1]CNCPS = Cornell Net Carbohydrate and Protein System; AFRC = Agriculture and Food Research Council.

[2]WOL = week of lactation; CI = concentrate intake (kg of DM/d); MY = milk yield (kg/d); MF = milk fat (%).

Therefore, we hypothesized that models constructed with observations obtained under conditions different from those commonly found in tropical environments may lack the accuracy and precision to predict DMI.

The objectives of the current study were (1) to develop a model to predict DMI in lactating dairy cows under Brazilian conditions with BW, milk production and composition, and DIM as independent variables in the model, and (2) to evaluate and compare the adequacy of the proposed model with 5 currently available DMI prediction models: 2 American-based: NRC (2001) and Cornell Net Carbohydrate and Protein System (**CNCPS**, version 6.0; Tylutki et al., 2008); 1 British-based: AFRC (1993); and 2 Brazilian-based: Freitas et al. (2006) and Santos et al. (2009), using an independent data set.

The data set used in the current study was built from observations reported in 100 studies (457 treatments means; 1,655 cows) published in Brazilian journals from 1991 to 2013 (76 studies) or reported in graduate student theses (24 studies). The criteria adopted for data inclusion in the data set were as follows: (1) experiment conducted under the tropical conditions of Brazil; (2) cows under different feeding management systems and production levels; (3) individual measurements of DMI; (4) estimation of pasture intake using external and internal markers to determine fecal output of DM; and (5) adequate description of cows (e.g., BW, DIM, milk yield, and composition) and experimental diets (e.g., ingredient and chemical composition). Specifically, the data set was composed of Holstein cows (72.6%) and Holstein × Zebu crosses (27.4%) fed either TMR (86%) or pasture (14%). Forages used by TMR-fed cows included corn silage (75.5%), sugarcane (12.7%), spineless cactus (*Opuntia ficus indica* Mill.) or spineless cactus plus corn silage (6.3%), sugarcane silage (1.4%), sorghum and sunflower silages (2.4%), and alfalfa silage or hay (1.7%). Forages grazed by pasture-fed cows included *Pennisetum purpureum* Schum. (35.3%), *Brachiaria* spp. (29.4%), *Panicum maximum* (21.6%), and *Cynodon* spp. (13.7%).

For statistical analysis, the data set was randomly divided into 2 subsets, with the first subset (60 studies; 309 treatments means; Appendix 1; development) used to develop a DMI prediction model and the second subset (40 studies; 148 treatments means; Appendix 2; evaluation) used to assess the adequacy of the new developed DMI prediction model compared with 5 currently available models (Table 1).

The DMI prediction model proposed herein was developed using a nonlinear mixed-model analysis of the reparameterized NRC (2001) model but including study as a random effect in the model. Specifically, the proposed nonlinear model was adjusted using metabolic BW ($BW^{0.75}$), 4% FCM, and DIM as fixed effects. Because the data set was built using observations from 60 studies with different breeds, feeding systems, environmental conditions, and experimental methodologies, it was necessary to quantify the variance associated with study, as well as to predict fixed effects adjusted for study effect. Therefore, each study in the data set was treated as a random sample from a larger population of studies (St-Pierre, 2001; Sauvant et al., 2008). Inclusion of study effects required estimation of both the fixed effects associated with the nonlinear model parameters and the random effects of study, similar to the approach described in Vyas and Erdman (2009). The nonlinear mixed (NLMIXED) procedure (Littell et al., 2006) of SAS (version 9.1; SAS Institute Inc., Cary, NC) was used to fit the model:

$$Y_{ij} = \left(\beta_1 \times BW^{0.75}{}_{ij} + \beta_2 \times 4\%\ FCM_{ij}\right) \times \left(1 - e^{[-\beta_3 \times (DIM_{ij} + \beta_4)]}\right) + exp_j + e_{ij},$$

where Y_{ij} = DMI of the ith DMI at the jth study with i ranging from 1 to 309, and j ranging from 1 to 60, $(\beta_1 \times BW^{0.75}{}_{ij} + \beta_2 \times 4\%\ FCM_{ij}) \times \left(1 - e^{[-\beta_3 \times (DIM_{ij} + \beta_4)]}\right)$ = fixed effect of model; β_1 and β_2 = coefficients representing the DMI per kilogram of $BW^{0.75}$ and per kilogram of 4% FCM, respectively; β_3 and β_4 = coefficients representing the adjustment for DIM; exp_j = random effect of study assuming a normal distribution; and e_{ij} = random error associated with each observation assuming a normal distribution. Data points were removed if the studentized residual was outside the range of −2.5