Predicting feed intake in confined beef cows

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Lay Summary

An accurate estimate of feed intake is a critical component in developing cost-effective, sustainable management systems and supplementation programs for beef cows. Equations currently being used to estimate feed intake in beef cows were generated using data published between 1979 and 1993. In an effort to evaluate the accuracy and precision of six previously published equations, we reviewed the literature and generated a validation data set restricted to studies either conducted or published since 2002. The final data set included 53 treatment means for nonlactating cows and 32 treatment means for lactating cows. None of the three published equations for nonlactating cows provided an accurate estimate of feed intake. However, the equation developed from Hibberd and Thrift (1992) performed well for lactating beef cows. The National Research Council (1996) equation underestimated feed intake substantially in lactating beef cows. A new prediction model was developed using the evaluation data set. Predictor variables in the new equation included stage of production, body weight, and diet energy concentration. This equation accounted for 68% of the variation in daily feed intake and may represent an improvement in prediction of feed intake for beef cows, although independent validation is needed.

Teaser Text

An independent data set was used to evaluate equations available to estimate feed intake in beef cows. One equation (Hibberd and Thrift, 1992) provided a reasonably accurate estimate of feed intake for lactating cows, although the equation from the same authors overestimated feed intake in nonlactating cows.
ABSTRACT:

Six existing equations (three for nonlactating and three for lactating; NRC, 1987; NRC, 1996 and Hibberd and Thrift, 1992) were evaluated for predicting feed intake in beef cows. Each of the previously published equations are sensitive to cow shrunk BW and feed energy concentration. Adjustments in feed intake prediction are provided for level of milk yield in the NRC 1987 and NRC 1996 equations. The equation published in 1996 used data generated between 1979 and 1993. Our objectives were to validate the accuracy of the published equations using more recent data and to propose alternative prediction models. Criteria for inclusion in the evaluation data set included projects conducted or published since 2002, direct measurement of feed intake, adequate protein supply, and pen feeding (no metabolism crate data). After removing outliers, the data set included 53 treatment means for nonlactating cows and 32 treatment means for lactating cows. Means for the nonlactating data set were DMI = 13.2 ± 2.9 kg/d, shrunk body weight = 578 ± 83.9 kg, body condition score = 5.7 ± 0.73, and Mcal NE\textsubscript{m}/kg of feed = 1.27 ± 0.15 Mcal/kg. Means for the lactating data set were DMI = 14.6 ± 2.24 kg/d, shrunk body weight = 503 ± 73.4 kg, body condition score = 4.7 ± 0.58, and Mcal NE\textsubscript{m}/kg feed = 1.22 ± 0.16. Simple linear regression was used to determine slope, intercept and bias when observed DMI (y) was regressed against predicted DMI (x). The NRC (1996) nonlactating equation underestimated feed intake in diets moderate to high in energy density with intercept differing from 0 and slope differing from one \((P = < 0.01)\). Average deviation from observed values was 2.4 kg/d. Similarly, when the NRC (1996) equation was used to predict DMI in lactating cows, the slope differed from one \((P < 0.01)\) with average deviation from observed values of 3.0 kg/d. New models were developed by
pooling the two data sets and including a categorical variable for stage of production (0 = nonlactating and 1 = lactating). Continuous variables included study-average shrunk body weight$^{0.75}$ and diet NE$_m$, Mcal/kg. The best-fit empirical model accounted for 68% of the variation in daily feed intake with standard error of the estimate $\text{Sy root mean squared error} = 1.31$. The proposed equation needs to be validated with independent data.

**Key words**: beef cow, dry matter intake, prediction equations
INTRODUCTION

An accurate estimate of feed intake is a fundamental component necessary to determine nutrient balance and project animal performance (Fox et al., 1995). In the beef cattle industry, large commercial feed yards, receiving yards and research institutions measure, monitor, and manage feed intake of growing and finishing cattle routinely. From these data sets, empirical models were developed and validated for the purpose of predicting feed intake of growing and finishing cattle (Anele et al., 2014; NRC, 1984; NRC, 1987; NRC, 1996; NASEM, 2016). Comparatively, little data is available to develop, validate and refine empirical models intended to predict feed intake in beef cows (NRC, 1987; Galyean and Gunter, 2016; Lalman et al., 2019). Extensive, non-confined management systems that predominate beef cow production in the U.S. limit direct feed intake measurement to research institutions and confinement housing conditions.

The National Academy of Sciences, Engineering, and Medicine (NASEM) beef cattle committee has published several equations intended to provide general guidance for feed intake of beef cows (NRC, 1984; NRC, 1987; NRC, 1996; NASEM, 2016). These equations included a considerable amount of feed intake data calculated from internal or external marker-based approaches. However, Neal et al. (1984) suggested that prediction equations using data from marker-based intake estimates were inferior to data sets containing direct measurements of intake along with relevant characteristics of animals and forage. One influential component in the most recent and widely used equation for beef cows (NRC, 1996; NASEM, 2016) is an adjustment for milk yield in lactating cows. This model component was adapted from dairy cow data (NRC, 1987) and has not been validated for beef cows. The objective of this work was to evaluate beef cow feed intake prediction equations using more recent data limited to direct measurement approaches.
MATERIALS AND METHODS

Data Screening

A literature search and screening process was conducted for recent beef cow forage or feed intake data. Published and unpublished data were identified through Journal of Animal Science, Translational Animal Science, Applied Animal Science, PubMed, Google Scholar, personal communication, and recent data sets from Oklahoma State University’s Range Cow Research Center. The first screening criteria imposed included only data based on voluntary, ad libitum feed intake management. The most recent beef cow intake equation recommended by NRC (1996) and NASEM (2016) was developed using experimental data collected from 1979 to 1993. Therefore, to avoid data sets used in that analysis, the second search criteria restricted inclusion to projects conducted or published between 2003 and 2022. A second objective for restricting inclusion to more recent studies was to capture potential long-term genetic and management changes that might influence feed intake in beef cows.

Third, only direct measurements of feed intake data were included. Challenges associated with marker-based feed intake data for grazing animals were recently reviewed by Galyean and Gunter (2016). Included in these challenges (potential sources of error) are relatively small numbers of experimental units per treatment mean, brief intake measurement periods, accurate determination of grazed diet nutritive value, potential for inconsistent marker dosing and/or incomplete marker recovery (Langlands et al., 1974; Cordova et al., 1978; Holechek et al., 1982). Coleman et al. (2014) suggested that alkanes may overestimate digestibility and therefore magnify intake estimates. While direct intake measurements overcome some of these problems, pen-based intake estimates suffer from some of the same challenges. For example, there is a plethora of published data employing a 10- to 14-d adaptation period followed by 5- to 7-d of direct feed intake measurement. To improve
accuracy for individual animal intake estimates within contemporary groups, the Beef Improvement Federation recommends 42 d of feed intake data collection to ensure a minimum of 35 d of reliable measurements. Additionally, feed intake determined in pen-fed animals does not reflect additional energy required for grazing activity and other behavioral differences (Coleman et al., 2014). We excluded studies using metabolism crate housing.

Fourth, only data from experiments identified as having provided adequate protein supply to meet ruminal and animal requirements were included. There were no screening criteria applied to diet forage or concentrate proportions. Diets included in the data set ranged from 35 to 100% forage (DM basis). Finally, studies reporting feed intake of lactating cows were required to include an estimate of milk yield.

After applying the selection criteria, available data sets predominantly utilized *Bos taurus* cattle with British or British/Continental breed influence. Data sources, number of means used from each experiment, and general classification for stage of production are provided in Table 1.

The qualitative data included average trial cow shrunken body weight (SBW), study-average body condition score when available (BCS; Wagner et al., 1988), dry matter intake (DMI), diet net energy for maintenance (NE_m, Mcal/kg), supplement DMI, supplement NE_m, and milk yield when applicable. Insufficient information was available to determine study-average days pregnant or days in milk in several experiments. Therefore, stage of production was limited to two classification variables: nonlactating or lactating. Unless SBW was described and reported directly, cow BW was converted to SBW by multiplying BW by 0.96 (NASEM, 2016). Reported diet NE_m values were used when available. In cases where NE_m was not reported, NE_m was calculated from diet composition according to ingredient tabular values (NASEM, 2016). Treatment or period mean, standard deviation (SD), minimum and
maximum values for both stages of production are shown in Table 2. Where supplement was provided, the contribution of supplement to daily DMI and NE\textsubscript{m} was included. Therefore, observed daily DMI and NE\textsubscript{m} intake represent the sum of contributions from the basal diet plus supplement.

**Calculations and Statistical Analysis**

A total of 98 (60 nonlactating and 38 lactating) treatment means met the screening criteria. Of the 60 nonlactating observations, nine represented cows that were described as non-pregnant, with the remaining classified as pregnant. Within stage of production, observations were further evaluated for outliers. Outliers were determined using residuals calculated by regressing observed DMI on predicted DMI with diet NE\textsubscript{m}, SBW\textsuperscript{0.75} and stage of production in the regression model. Outliers were defined as observations with studentized residuals greater than three (in absolute value; SAS Inst. Inc., Cary, NC).

Three prediction equations for gestating cows and three prediction equations for lactating cows were evaluated: NRC 1987-Eq. A, NRC 1996-Eq. B, and Hibberd and Thrift 1992-Eq. C and D (Table 3). The Hibberd and Thrift (1992) feed intake guidelines for beef cows were first presented in tabular form and have been used for many years in extension and popular press publications. These guidelines were approximated in graphical form in the NASEM (2016) publication and subsequently, regression equations were developed using the original tabular values (T.A. Thrift, personal communication, September 2018). Resulting equations are shown in the footnotes for Table 3.

Evaluation for each of the six equations was performed using the PROC REG procedure in SAS (v. 9.4; SAS Inst. Inc., Cary, NC, 2013). Observed DMI values (y; kg / d) were regressed against predicted DMI values (x; kg/d) according to (Piñeiro et al., 2008):
\[ y'i - y_i = a + b'y_i + \varepsilon_i \]

An F-test \((P < 0.05)\) was used to determine null hypotheses intercept \(a = 0\) and slope \(b = 1\). If the slope is statistically different from 1 (null hypothesis is rejected), the predicted values are not consistently related to observed values. Similarly, if the slope is not different from 1 but the intercept is statistically different from 0, then the model is biased, consistently under- or overestimating daily DMI. If both null hypotheses are accepted \((P > 0.05)\), then disagreement between observed and predicted values are due to unexplained variance (Piñeiro et al., 2008).

The coefficient of determination for simple linear regression \(r^2\) was calculated as an indication of the proportion of the linear variation of observed values \(y\) explained by the variation of predicted values \(x\). Root mean squared deviation (RMSD) was calculated to determine the deviation of predicted values against the \(y = x\) or unity line expressed in the same units as the model variable (kg/d; Kobayashi and Salam, 2000; Gauch et al., 2003; Piñeiro et al., 2008).

Two new feed intake prediction models were developed using the evaluation data set. The first approach was like that employed by NRC (1996), where a prediction equation was produced to estimate daily kcal NE\(_m\) intake / kg SBW\(^{0.75}\) (NEMI). Total NE\(_m\) intake was determined as the product of DMI and dietary NE\(_m\), Mcal/kg. Candidate predictor variables included diet NE\(_m\), NE\(_m\)^2, a class variable for stage of production (STAGE; 0 = nonlactating, 1 = lactating), and the interaction of NE\(_m\) by STAGE. Stage of gestation (1\(^{st}\), 2\(^{nd}\), or 3\(^{rd}\) trimester) and stage of lactation (early or late) were not included because of lack of uniformity in timing for feed intake measurement within STAGE. Similarly, milk yield was not included as a predictor variable because of the lack of uniformity among experimental protocols in terms of timing (early, mid, or late lactation) and milk yield measurement.
procedures. Predicted daily NEMI was then divided by diet NE\textsubscript{m} to estimate daily feed intake, kg/d. In the second approach, a prediction equation was developed to estimate feed DMI (kg/d) directly. Predictor variables included SBW\textsuperscript{0.75}, diet NE\textsubscript{m}, diet NE\textsubscript{m}\textsuperscript{2}, STAGE, NE\textsubscript{m} by STAGE, and SBW\textsuperscript{0.75} by STAGE. Coefficient of determination (r\textsuperscript{2}) and standard error of the estimate (Sy.x) were used to determine goodness-of-fit for the new models.

The CALIS procedure of SAS (v. 9.4; SAS Inst. Inc., Cary, NC, 2013) was used to develop standardized path coefficients between components in the models. Path coefficient probabilities were calculated using a t test. Diet NE\textsubscript{m} and STAGE were exogenous variables meaning their variance was not determined by other variables in the model. Dry matter intake and SBW\textsuperscript{0.75} were treated as endogenous variables indicating their variance was determined by other variables in the model.

**RESULTS AND DISCUSSION**

*Data screening*

In one experiment, feed intake was measured for nonlactating, nonpregnant cows first consuming grass hay, then later consuming corn silage (Martin et al., 2019). The mean for corn silage intake was removed from the data set because feed intake of the corn silage was unreasonably low and met the criteria for exclusion as an outlier. In addition, six treatment means for gestating and six treatment means for lactating cows consuming a pelleted straw/alfalfa hay or pelleted alfalfa hay diet, respectively, met the exclusion criteria due to exceptionally high feed intake (Parsons et al., 2021). These modifications resulted in the availability of 53 observations for nonlactating cows with a range in diet NE\textsubscript{m} of 0.93 to 1.54 Mcal/kg and 32 observations for lactating cows with a range of diet NE\textsubscript{m} of 0.99 to 1.49 Mcal / kg.
Evaluation of existing equations for nonlactating beef cows

Results from regressing predicted feed intake for nonlactating cows against observed feed intake values are shown in Fig. 1 and Table 3. The intercept differed \((P = 0.05)\) from 0 for Eq. B, while the slope differed \((P < 0.01)\) from 1 for all three equations. Interestingly, all three equations provided reasonable estimates of feed intake at the lower range of diet energy concentration. Equations A and B underestimated feed intake while Eq. C overestimated feed intake with increasing diet energy density. While predictions from Eq. A explained more of the variation in observed values compared to Eq. B and C, the average error of prediction ranged from 2.4 to 3.1 kg/d (RMSD), suggesting lack of fit for all three equations. The fit statistic, RMSD, should not be confused with standard error of the estimate (Sy.x), which in this case is the same statistic as root mean squared error (RMSE) because there is only one parameter in the regression model. Root mean squared deviation is an estimate of the average error between observed values and the unity line or \(y = x\). In contrast, RMSE is a measure of the average error or deviation between observed values and the line derived from regressing \(y\) on \(x\). Therefore, RMSD can only equal RMSE if the regression is perfect (intercept = 0 and slope = 1.0). Otherwise, RMSD will be larger than RMSE. Therefore, RMSD calculated by regressing observed \((y)\) against predicted \((x)\) values, provides a better evaluation of model performance when prediction is the objective (Piñeiro et al., 2008). For example, even though the RMSE (1.9, data not shown) for Eq. A, is lower than Eq. B and C (2.1, data not shown), Eq. A produced inaccurate predictions of forage intake with average error of 3.1 kg per day.

Prediction error for Eq. A and C can be attributed to a combination of bias and unexplained variance (Table 4). In contrast, a large percentage of Eq. B prediction error was from unexplained variance.
Equation A was developed using the data of Vona et al. (1984). In that experiment, mature, nonlactating beef cows were fed long-stemmed warm-season grass hays harvested at different stages of maturity. This data set has several unique characteristics rarely found in the literature. First, 35 different hay lots were fed over two years with a wide range in NEm (0.76 to 1.78 Mcal/kg; NRC, 1996). Secondly, forage intake and fecal output were measured directly, resulting in a relatively large data set employing in vivo forage intake and apparent digestibility methods. Nevertheless, several factors could contribute to the substantial underprediction of the more recent data using the equation derived from this classical data set. Fifteen of the 35 hay lots contained less than 8% crude protein (DM basis) with nine lots containing between 4.8% and 7.5% crude protein (DM basis; Vona et al., 1984). It is well established that feed intake and diet digestibility are negatively impacted with forage diets containing less than about 7.5% crude protein (McCollum and Horn, 1990; Moore and Kunkel, 1995). Secondly, in the work of Vona et al. (1984), all forages were fed unprocessed with no indication of concentrate supplementation. In contrast, the current nonlactating evaluation data set includes 10 of 19 experiments where the forage was processed and, in many cases, blended with concentrate feeds and (or) a liquid molasses-based supplement. Because the Vona data set represents approximately 23% of the data used to derive Eq. B (NRC, 1996), these same factors could contribute to the modest underprediction when Eq. B was evaluated.

**Evaluation of existing equations for lactating beef cows**

Parameter estimates for regressing observed feed intake against predicted feed intake of lactating cows are provided in Table 3 and a graphical representation is provided in Fig. 2. While the predicted values using Eq. D explained 75% of the variation in observed values and the intercept did not differ from 0, this model was highly inaccurate with a large RMSD.
due primarily to bias (95%; Tables 3 and 4). As can be seen in Fig. 2, Eq. D grossly underestimated feed intake in all cases. Results from this evaluation reveal the utility of RMSD in evaluating model fit for the purpose of prediction. Regressing observed values against predicted values for Eq. D gives RMSD = 4.1 kg/d average distance from the unity line. For perspective, RMSE = 2.2 kg/d, indicating the observed values are much closer to the derived least squares regression line (as expected) while remaining distant from the unity line.

Equation E had relatively large RMSD (3.0 kg/d) with a slope significantly different from 1.0 ($P = 0.001$). Like Eq. D, most of the prediction error was explained by underprediction bias (79%).

As can be seen in Fig. 2, the regression line for Eq. F crossed the unity line near the center of observed values. As a result, overall prediction error was lower compared to Eq. D and E. However, both the intercept and slope differed ($P < 0.01$) from 0 and 1, respectively. These results indicate that this equation provided reasonably accurate estimates of feed intake overall, with slight underprediction of feed intake at the lower end of the range in observed values and slight overprediction of feed intake at the higher end of the range in observed values.

Equations A and B are adjusted to a lactating cow basis using a constant to account for increased feed intake relative to milk yield (NRC, 1996; NASEM, 2016). The suggested constant is equal to 0.2 kg for each 1 kg of milk yield. Therefore, assuming the general effects of milk yield, cow weight and diet energy density are independent, any bias associated with the gestation evaluation results should be reflected in the lactating cow evaluation results because the same coefficients are used. This carryover likely explains some of the
dramatic negative bias in Eq. A and B when applied to lactating cows. The 0.2 kg adjustment was first proposed by the ARC (1980) and NRC (1987) using data from dairy cows.

New model development

The best-fit equation to predict daily NEMI included a linear term for diet NE$_m$ and an intercept adjustment for STAGE:

\[
NEMI = 0.224 \pm 0.013 \times NE_m + 0.0346 \pm 0.005 \times STAGE - 0.142 \pm 0.017
\]

Eq. G

where NEMI = daily NE$_m$ intake, kcal/kg SBW$^{0.75}$ and STAGE = 0 for nonlactating and 1 for lactating cows. The interaction term was not significant ($P = 0.42$) and subsequently removed from the model. Each model component is significant at $P < 0.01$. This model accounted for 79% of the variation (adjusted $R^2$) in daily NEMI. When both the linear and the quadratic term for NE$_m$ was included in the model, the curve characterizing predicted feed intake (kg/d) produced an illogical concave-shaped curve when plotted against diet NE$_m$. This resulted in feed intake (kg/d) predicted to increase at both extremes of the NE$_m$ range. Therefore, this model was considered to be overparameterized and not presented.

Predicted daily NEMI was divided by diet NE$_m$ concentration to provide estimates of daily feed intake, kg/d. Subsequently, predicted feed intake values were regressed against observed feed intake values resulting in adjusted $r^2 = 0.67$ and Sy.x = 1.34 kg/d.

The best-fit equation for predicting feed intake (kg/d) directly included linear terms for diet NE$_m$ and SBW$^{0.75}$ and an intercept adjustment for STAGE:

\[
DMI = 3.27 \pm 0.44 \times STAGE + 9.21 \pm 1.18 \times NE_m + 0.133 \pm 0.017 \times SBW^{0.75} - 14.38 \pm 2.19
\]

Eq. H

where DMI = dry matter intake, kg/d, STAGE = 0 for nonlactating and STAGE = 1 for lactating cows, NE$_m$ = diet NE$_m$, Mcal/kg, and SBW$^{0.75}$ = shrunk body weight$^{0.75}$, kg. The interaction terms were not significant ($P > 0.27$) and were removed from the model. Each
predictor variable remaining in the model was significant at $P < 0.01$. The final model (Eq. H) resulted in adjusted $R^2 = 0.68$ and $Sy.x = 1.31$.

Path analysis indicated a modest positive indirect effect of diet NE$_m$ on DMI through SBW$^{0.75}$ ($P < 0.05$) indicating cattle that consumed energy-dense diets during the study period were heavier and consumed more feed. However, diet NE$_m$ also resulted in a strong positive direct effect on DMI ($P < 0.001$) as previously reported (NASEM, 2016).

STAGE had a negative indirect effect on DMI ($P < 0.001$) due to lactating cows weighing less than nonlactating cows. However, there was a strong positive direct effect of STAGE, indicating lactation increased DMI ($P < 0.001$). Also as previously reported (NASEM, 2016), SBW$^{0.75}$ had a strong positive direct effect on DMI.

For the 21 treatment means where milk yield was measured by a milking machine, milk yield was $7.3 \pm 2.3$ kg. In the 11 treatment means available using the weigh-suckle-weigh technique, milk yield was $5.2 \pm 1.8$ kg with an overall mean of $6.56 \pm 2.3$ kg. Thus, using the overall mean, the average increase in feed intake per kg milk yield is 0.50. Using the yield from machine measurements, feed intake increases, on average, 0.45 kg per kg milk yield. These values are similar to those reported by Johnson et al. (2003; 0.33 and 0.37) and Coleman et al. (2014; 0.55) and substantially greater than the 0.2 kg increase in feed intake per kg milk yield recommended by NASEM (2016).

The adjustment for lactation in Eq. H (3.27 kg/d) represents a 21% increase in feed intake for a 545 kg lactating cow consuming a diet with 1.3 Mcal NE$_m$ with mean milk yield of 6.56 kg/d. This compares to 1.31 kg/d or 10% increase for the same inputs applied in the current Beef Cattle Nutrient Requirements Model (NASEM, 2016). The increased energy and feed intake required for lactation is associated with energy required to produce milk as well as the increased metabolic activity associated with lactation. For example, maintenance energy requirement has been reported to increase by 5% (Wiseman et al., 2019) to 38%
(Neville, 1974) and therefore, maintenance energy requirement in the Beef Cattle Nutrient Requirements Model (NASEM, 2016) is increased by 20% during lactation. This represents an increase of about 2.2 Mcal NE\textsubscript{m} requirement per day during lactation. In an extensive literature review, the NASEM (2016) committee reported average energy concentration in milk was 0.72 Mcal/kg. Therefore, with mean milk yield of 6.56 kg for these experiments, energy required for lactation is about 6.9 Mcal NE\textsubscript{m} per day (6.56 \times 0.72 + 2.2). Given a diet with 1.3 Mcal NE\textsubscript{m}/kg, the feed intake adjustment for lactation given in Eq. H results in increased energy intake of about 4.3 Mcal NE\textsubscript{m} per day (3.27 \times 1.3). When cows consume a diet moderate in energy density, the feed intake response to lactation is not adequate to offset increased energy demand; diet NE\textsubscript{m} concentration must be increased to avoid negative energy balance.

The relationship between predicted feed intake and diet energy concentration are depicted in Fig. 4 for nonlactating cows for Eq. A (NRC, 1987), Eq. B (NRC, 1996), Eq. C (Hibberd and Thrift, 1992), and equations generated from this validation data set (Eq. G and H). Similarly, the same relationships are depicted in Fig. 5 for lactating cows using Eq. D (NRC, 1987), E (NRC, 1996), F (Hibberd and Thrift, 1992), as well as the two new models. The graphical representation reveals the overestimation of feed intake produced by Eq. C up to about 1.4 Mcal of diet NE\textsubscript{m}. Equations C and F are unique in the stabilizing response to increased diet energy concentration at about 1.4 Mcal NE\textsubscript{m}. The response in cows projected by Eq. C and F is similar to the response in growing and finishing beef cattle where feed intake is projected to stabilize between 1.4 to 1.6 Mcal NE\textsubscript{m} and decline with diet NE\textsubscript{m} > 1.6 Mcal (NRC, 1984; NRC, 1996). This contrasts with Eq. B, which predicts escalating feed intake when diet energy concentration is beyond about 1.3 Mcal NE\textsubscript{m}. The data set used to develop Eq. B has the advantage of a wider range in diet NE\textsubscript{m} (0.76 to 2.08 Mcal NE\textsubscript{m})
compared to the current evaluation data set. Clearly, more work is needed to accurately predict feed intake when cows consume high-quality forage or energy-dense mixed diets.

Figure 4 also reveals that Eq. G may underestimate feed intake in nonlactating cows when diet energy concentration is < 1.0 Mcal/kg. For example, with NE$_m$ = 0.9 (48 % TDN), Eq. G predicts nonlactating cows would consume only 1.35% of SBW. However, with diet energy > 1.1 Mcal/kg, DMI predictions are similar for Eq. G and Eq. H (Fig. 4).

CONCLUSION

Previously published equations (NRC, 1987 and NRC, 1996) produced reasonable estimates of feed intake in confined, nonlactating and lactating beef cows only when observed feed intake and (or) diet feed energy concentration was low. These equations dramatically underestimated feed intake when observed feed intake and (or) dietary energy concentration was high. In contrast, the Hibberd and Thrift (1992) equation consistently overestimated feed intake in nonlactating cows, while providing reasonable estimates of feed intake in lactating cows. The new empirical equation (Eq. H) may provide a more accurate estimate of DMI when dietary protein is adequate and within a range of diet energy common to extensive cow/calf production systems. However, validation is necessary for the new equations, particularly over a wide range in diet energy concentration. Furthermore, characterization of the effects of body composition, grazing activity, forage processing, and milk yield are needed to improve prediction precision and accuracy.

DISCLOSURES

The authors declare no conflicts of interest.
LITERATURE CITED


FIGURE LEGEND

Figure 1. Relationship of observed to predicted feed intake in nonlactating cows using Eq. A (NRC, 1987), Eq. B (NRC, 1996), and Eq. C (Hibberd and Thrift, 1992).

Figure 2. Relationship of observed to predicted feed intake in lactating beef cows using Eq. D (NRC, 1987), Eq. E (NRC, 1996), and Eq. F (Hibberd and Thrift, 1992).

Figure 3. Path analysis to determine the relationship between diet NE_m (Mcal/kg), stage of production (STAGE = nonlactating or lactating), shrunk metabolic body weight (SBW^{0.75}), and dry matter intake (DMI, kg/d). Standardized path coefficients are shown and significant at $P < 0.001$ (***), and $P < 0.05$ (*).

Figure 4. Predicted feed intake response to increasing diet NE_m for 545 kg nonlactating beef cows (dashed line = Eq. A, NRC 1987; diamonds = Eq. B, NRC 1996; triangles = Eq. C, Hibberd and Thrift 1992; squares = Eq. G; circles = Eq. H).

Figure 5. Predicted feed intake for 545 kg beef cows producing 7 kg milk/d (dashed line = Eq. A, NRC 1987; diamonds = Eq. B, NRC 1996; triangles = Eq. C, Hibberd and Thrift 1992; squares = Eq. G; circles = Eq. H).
Table 1. Summary of sources for beef cow feed intake data

<table>
<thead>
<tr>
<th>First Author, Year</th>
<th>Source</th>
<th>No. of Treatment Means</th>
<th>Stage of Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andresen, 2020</td>
<td>J</td>
<td>2</td>
<td>Gestation</td>
</tr>
<tr>
<td>Banta, 2008</td>
<td>J</td>
<td>5</td>
<td>Gestation</td>
</tr>
<tr>
<td>Briggs, 2022</td>
<td>J</td>
<td>1</td>
<td>Gestation</td>
</tr>
<tr>
<td>Cassaday, 2016</td>
<td>T</td>
<td>4</td>
<td>Gestation</td>
</tr>
<tr>
<td>Freely, 2019</td>
<td>U</td>
<td>3</td>
<td>Gestation</td>
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<td>Nonpregnant/nonlactating</td>
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<td>Gestation</td>
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<td>Holder, 2017</td>
<td>U</td>
<td>2</td>
<td>Gestation</td>
</tr>
<tr>
<td>Holder, 2018</td>
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<td>2</td>
<td>Gestation</td>
</tr>
<tr>
<td>Holder, 2019</td>
<td>T</td>
<td>2</td>
<td>Gestation</td>
</tr>
<tr>
<td>Holder, 2022</td>
<td>J</td>
<td>2</td>
<td>Gestation</td>
</tr>
<tr>
<td>Holder, 2020</td>
<td>T</td>
<td>2</td>
<td>Gestation</td>
</tr>
<tr>
<td>Holder, 2022</td>
<td>J</td>
<td>2</td>
<td>Gestation</td>
</tr>
<tr>
<td>Jarstedt, 2018</td>
<td>J</td>
<td>2</td>
<td>Nonpregnant/nonlactating</td>
</tr>
<tr>
<td>Johnson, 2003</td>
<td>J</td>
<td>4</td>
<td>Gestation</td>
</tr>
<tr>
<td>Martin, 2019</td>
<td>J</td>
<td>1</td>
<td>Gestation</td>
</tr>
<tr>
<td>Moehlenpah, 2021</td>
<td>J</td>
<td>5</td>
<td>Nonpregnant/nonlactating</td>
</tr>
<tr>
<td>Moore, 2022</td>
<td>T</td>
<td>1</td>
<td>Gestation</td>
</tr>
<tr>
<td>Mourer, 2012</td>
<td>T</td>
<td>2</td>
<td>Gestation</td>
</tr>
<tr>
<td>Sexten, 2021</td>
<td>J</td>
<td>4</td>
<td>Gestation</td>
</tr>
<tr>
<td>Walker, 2015</td>
<td>J</td>
<td>2</td>
<td>Gestation</td>
</tr>
<tr>
<td>Warren, 2017</td>
<td>T</td>
<td>3</td>
<td>Gestation</td>
</tr>
<tr>
<td>Black, 2013</td>
<td>J</td>
<td>3</td>
<td>Lactation</td>
</tr>
<tr>
<td>Cassaday, 2016</td>
<td>T</td>
<td>2</td>
<td>Lactation</td>
</tr>
<tr>
<td>Gross, 2019</td>
<td>T</td>
<td>1</td>
<td>Lactation</td>
</tr>
<tr>
<td>Gross, 2020</td>
<td>T</td>
<td>1</td>
<td>Lactation</td>
</tr>
<tr>
<td>Holder, 2019</td>
<td>T</td>
<td>1</td>
<td>Lactation</td>
</tr>
<tr>
<td>Holder, 2021</td>
<td>T</td>
<td>2</td>
<td>Lactation</td>
</tr>
<tr>
<td>Johnson, 2003</td>
<td>J</td>
<td>4</td>
<td>Lactation</td>
</tr>
<tr>
<td>Johnson, 2003</td>
<td>J</td>
<td>4</td>
<td>Lactation</td>
</tr>
<tr>
<td>Moore, 2022</td>
<td>T</td>
<td>1</td>
<td>Lactation</td>
</tr>
<tr>
<td>Mourer, 2012</td>
<td>T</td>
<td>2</td>
<td>Lactation</td>
</tr>
<tr>
<td>Mourer, 2012</td>
<td>T</td>
<td>2</td>
<td>Lactation</td>
</tr>
<tr>
<td>Walker, 2015</td>
<td>J</td>
<td>2</td>
<td>Lactation</td>
</tr>
<tr>
<td>Williams, 2018</td>
<td>T</td>
<td>4</td>
<td>Lactation</td>
</tr>
<tr>
<td>Winterholler, 2009</td>
<td>J</td>
<td>3</td>
<td>Lactation</td>
</tr>
</tbody>
</table>

1 Source: J = journal; T = thesis, abstract, or research report; U = unpublished data
Table 2. Mean, standard deviation, minimum and maximum for observed variables

<table>
<thead>
<tr>
<th>Item</th>
<th>Number of treatment means</th>
<th>Mean</th>
<th>STD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nonlactating</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cow SBW, kg(^a)</td>
<td>53</td>
<td>589</td>
<td>76.7</td>
<td>420</td>
<td>730</td>
</tr>
<tr>
<td>BCS(^b)</td>
<td></td>
<td>5.8</td>
<td>0.75</td>
<td>4.4</td>
<td>7.5</td>
</tr>
<tr>
<td>DMI, kg(^c)</td>
<td></td>
<td>12.9</td>
<td>2.90</td>
<td>8.3</td>
<td>20.6</td>
</tr>
<tr>
<td>Diet NE(_m), Mcal/kg(^d)</td>
<td></td>
<td>1.25</td>
<td>0.16</td>
<td>0.93</td>
<td>1.54</td>
</tr>
<tr>
<td><strong>Lactating</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cow BW, kg(^a)</td>
<td>32</td>
<td>510</td>
<td>69.3</td>
<td>404</td>
<td>692</td>
</tr>
<tr>
<td>BCS(^b)</td>
<td></td>
<td>4.8</td>
<td>0.58</td>
<td>4.1</td>
<td>6.9</td>
</tr>
<tr>
<td>DMI, kg(^c)</td>
<td></td>
<td>14.4</td>
<td>2.1</td>
<td>10.3</td>
<td>19.2</td>
</tr>
<tr>
<td>Diet NE(_m), Mcal/kg(^d)</td>
<td></td>
<td>1.21</td>
<td>0.15</td>
<td>0.99</td>
<td>1.49</td>
</tr>
<tr>
<td>Daily milk yield, kg</td>
<td></td>
<td>6.56</td>
<td>2.3</td>
<td>3.0</td>
<td>11.3</td>
</tr>
</tbody>
</table>

\(^a\)Study-average shrunk body weight, kg.
\(^b\)Body condition score, scale = 1 to 9 (Wagner et al., 1988).
\(^c\)Feed intake, kg/d (dry matter basis).
\(^d\)Diet net energy for maintenance, Mcal/kg.
Table 3. Parameter estimates for regression of observed feed intake on predicted feed intake (kg DM/d) for gestating and lactating beef cows

<table>
<thead>
<tr>
<th>Stage</th>
<th>Equation</th>
<th>( r^2 )</th>
<th>RMSD(^a)</th>
<th>Intercept(^b)</th>
<th>Slope(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gestation</td>
<td>Eq A (NRC, 1987)(^d)</td>
<td>0.56</td>
<td>3.1</td>
<td>-1.84 ± 1.8</td>
<td>1.40 ± 0.17</td>
</tr>
<tr>
<td></td>
<td>Eq B (NRC, 1996)(^e)</td>
<td>0.46</td>
<td>2.4</td>
<td>-5.33 ± 2.7</td>
<td>1.52 ± 0.23</td>
</tr>
<tr>
<td></td>
<td>Eq C (Hibberd and Thrift, 1992)(^f)</td>
<td>0.47</td>
<td>2.8</td>
<td>0.35 ± 1.9</td>
<td>0.85 ± 0.13</td>
</tr>
<tr>
<td>Lactation</td>
<td>Eq D (NRC, 1987)(^g)</td>
<td>0.75</td>
<td>4.1</td>
<td>1.89 ± 1.1</td>
<td>1.19 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>Eq E (NRC, 1996)(^h)</td>
<td>0.66</td>
<td>3.0</td>
<td>-1.5 ± 2.2</td>
<td>1.36 ± 0.18</td>
</tr>
<tr>
<td></td>
<td>Eq F (Hibberd and Thrift, 1992)(^i)</td>
<td>0.67</td>
<td>1.5</td>
<td>4.85 ± 1.2</td>
<td>0.68 ± 0.09</td>
</tr>
</tbody>
</table>

\(^a\)RMSD = Root mean squared deviation expressed as kg/d.
\(^b\)Intercept ± SE. Bold font indicates intercept values significantly different from 0 at \( P < 0.05 \).
\(^c\)Linear regression coefficient ± SE. Bold font indicates coefficients significantly different from 1 at \( P < 0.05 \).
\(^d\)Eq. A: DMI, kg / d = SBW\(^{0.75}\), kg \* (0.0194 + 0.0545 \* NE\(_{m}\), Mcal/kg).
\(^e\)Eq. B: DMI, kg / d = (SBW\(^{0.75}\), kg \* (0.04997 \* NE\(_{m}\)^2 + 0.04631)) / NE\(_{m}\), Mcal/kg.
\(^f\)Eq. C: DMI, kg / d = (0.0323 \* NE\(_{m}\)^2, Mcal/kg + 0.0944 \* NE\(_{m}\), Mcal/kg – 0.0418) \* SBW, kg.
\(^g\)Eq. D: DMI, kg / d = SBW\(^{0.75}\), kg \* (0.0194 + 0.0545 \* NE\(_{m}\), Mcal/kg) + 0.2 \* milk yield, kg/d.
\(^h\)Eq. E: DMI, kg / d = ((SBW\(^{0.75}\), kg \* (0.04997 \* NE\(_{m}\)^2 + 0.04631) + 0.2 \* milk yield, kg/d)) / NE\(_{m}\), Mcal/kg.
\(^i\)Eq. F: DMI, kg / d = (-0.0261 \* NE\(_{m}\)^2 + 0.07777 \* NE\(_{m}\) - 0.0277) \* SBW, kg.
Table 4. Squared sum of prediction error and Theil’s partial inequality coefficients for regression of observed on predicted feed intake (kg DM/d) in gestating and lactating beef cows

<table>
<thead>
<tr>
<th>Stage</th>
<th>Prediction Equation</th>
<th>SSPE(^a)</th>
<th>U(_{\text{bias}}), %(^b)</th>
<th>U(_{\text{slope}}), %(^b)</th>
<th>U(_{\text{error}}), %(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gestation</td>
<td>Eq A (NRC, 1987)(^c)</td>
<td>515</td>
<td>59</td>
<td>4</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Eq B (NRC, 1996)(^d)</td>
<td>302</td>
<td>15</td>
<td>8</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>Eq C (Hibberd and Thrift, 1992)(^e)</td>
<td>416</td>
<td>43</td>
<td>2</td>
<td>55</td>
</tr>
<tr>
<td>Lactation</td>
<td>Eq D (NRC, 1987)(^f)</td>
<td>534</td>
<td>95</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Eq E (NRC, 1996)(^g)</td>
<td>277</td>
<td>79</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Eq F (Hibberd and Thrift, 1992)(^h)</td>
<td>69</td>
<td>6</td>
<td>22</td>
<td>72</td>
</tr>
</tbody>
</table>

\(^a\) SSPE = Squared sum of prediction error.

\(^b\) Theil’s coefficients reflecting proportion of variance of observed values not explained by the predicted values (SSPE) partitioned into U\(_{\text{bias}}\), the proportion associated with mean differences between observed and predicted values, U\(_{\text{slope}}\), the proportion associated with the slope of the fitted model and the y = x line, and U\(_{\text{error}}\), the proportion associated with the unexplained variance.

\(^c\) Eq. A: DMI, kg / d = SBW\(^{0.75}\), kg * (0.0194 + 0.0545 * NE\(_m\), Mcal/kg).

\(^d\) Eq. B: DMI, kg / d = (SBW\(^{0.75}\), kg * (0.04997 * NE\(_m^2\) + 0.04631)) / NE\(_m\), Mcal/kg.

\(^e\) Eq. C: DMI, kg / d = (-0.0323 * NE\(_m^2\), Mcal/kg + 0.0944 * NE\(_m\), Mcal/kg – 0.0418) * SBW, kg.

\(^f\) Eq. D: DMI, kg / d = SBW\(^{0.75}\), kg * (0.0194 + 0.0545 * NE\(_m\), Mcal/kg) + 0.2 * milk yield, kg/d.

\(^g\) Eq. E: DMI, kg / d = ((SBW\(^{0.75}\), kg * (0.04997 * NE\(_m^2\) + 0.04631) + 0.2 * milk yield, kg/d)) / NE\(_m\), Mcal/kg.

\(^h\) Eq. F: DMI, kg / d = (-0.0261 * NE\(_m^2\) + 0.07777 * NE\(_m\) - 0.0277) * SBW, kg.
Figure 1

- Eq. A; NRC 1987
- Eq. B; NRC 1996
- Eq. C; Hibberd and Thrift
Figure 2

Equation D; NRC 1987

Equation E; NRC 1996

Equation F; Hibberd and Thrift
Figure 5