PREDICTING DRY MATTER INTAKE OF GESTATING AND LACTATING BEEF COWS

By

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PREDICTING DRY MATTER INTAKE OF

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Abstract: In 1996, the NASEM beef cattle committee developed and published an equation to estimate cow feed intake using results from studies conducted or published between 1979 and 1993. The same equation was recommended for use in the most recent version of this publication in 2016. The equation utilizes body weight (BW), diet digestibility and milk yield. Our objective was to validate the accuracy of the NASEM equation using recently published and unpublished data. Criteria for inclusion in the validation data set included projects conducted or published since 2002, direct measurement of forage intake, adequate protein supply, and pen feeding (no tie stall or metabolism crate data). The validation data set included 48 treatment means for nonlactating cows and 29 treatment means for lactating cows. Quantitative data collected for the nonlactating data set included BW (593 ± 78.1 kg), BCS (5.7 ± 0.73), and Mcal NEm per kg of feed (1.26 ± 0.16 Mcal/kg) and lactating data set included DMI (12.7 ± 2.98 kg) and BW (505 ± 62.4 kg), BCS (4.6 ± 0.44), NEm per kg feed (1.25 ± 0.24 Mcal), and DMI (14.3 ± 2.08 kg), respectively. Non-intercept models were used to determine slope and bias when predicted DMI was regressed against observed DMI. The slope for linear bias in the NASEM nonlactating equation differed from 1 ($P = < 0.0001$) with a 13.9 percent downward bias. Similarly, when the NASEM equation was used to predict DMI in lactating cows, the slope differed from 1 ($P < 0.0001$) with a downward bias of 16.6 percent. Therefore, new prediction models were developed for both nonlactating and lactating cows. Log and exponential transformations were used to correct for heteroskedasticity. The best-fit nonlactating and lactating equations seem to provide need to be further validated with independent data sets. The current NASEM equation for predicting intake underestimated feed intake for both gestating and lactating beef cows. The new equation may improve the accuracy of predicting cow feed or forage consumption.

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FORMAT OF THESIS

This thesis is presented in Journal of Animal Science style and format. Use of this format allows the individual chapters to be suitable for submission to scientific journals. One paper has been prepared from the data collected and includes an abstract, introduction, materials and methods, results and discussion, and literature cited section. This paper is chapter II.

CHAPTER I

LITERATURE REVIEW

Introduction

A fundamental component of beef cattle nutrition and diet formulation is the understanding of factors affecting feed intake. This is a challenge for grazing situations and situations where animals are provided ad-libitum access to forages and other roughages because feed consumption is not regularly measured or monitored daily by feeding equipment such as that used for pen-fed animals. Additionally, in most situations, feed intake of grazing cattle is not directly controlled whereas the manager can limit the amount of feed available to a group of animals fed in a pen. Intake is affected by diet nutritive value and digestibility, physical form, passage rate, digestion rate, physiological demands, and environmental stressors. The objective of this review is to discuss published research documenting factors influencing average daily feed intake of beef cows.

Diet factors influencing forage intake in beef cows

Energy and Digestibility of Diet

Energy in beef cow diets is often characterized as total digestible nutrients (TDN), metabolizable energy (ME), and net energy (NE). Net energy is either released as heat or retained for a product such as milk or weight gain (Ferrell and Oltjen 2008). Systems that measure the energy available for use based on feed values and animal needs have been developed. These included the total digestible nutrient (TDN) system commonly used in beef cow nutrition. Diet energy is commonly quantified using TDN in cattle nutrition (Cooke, 2018). The energy values of feed for the TDN system are calculated from digestible fraction of crude protein, fiber, nitrogen-free extract, and ether extract (Ferrell and Oltjen, 2008). Burskirk (1992) reported that lactating angus beef cows eating higher energy diets (1145 Mcal body energy) ate 5.4 % of BW DMI and low energy diets (578.4 Mcal body energy) ate 2.7 % of BW. High energy and low energy diets had a 13 kg difference in intake at 95 d postpartum. High and low energy cows held at maintenance also had a significant difference.

Diet digestibility has been shown to be influenced by level of feed intake and diet composition (Colucci et al., 1982). Increased intake leads to decreased digestibility due to increased passage rate of the digesta (Moe et al., 1965; Colucci et al., 1982; Shaver et al., 1986; Okine and Mathison, 1991). Colucci (1982) conducted a trial using dry and lactating dairy cows. Half of the cows from each group were fed low forage to concentrate ratio diets and the other half were fed high forage to concentrate ratio diets. Dry cows were fed at an energy intake level for maintenance and lactating cows were fed ad libitum. Digestibility was lower at higher intake levels due to passage rate through digestive tract. Digestibility of gross energy was correlated with retention time. Okine and Mathison used four nonlactating Holstein dairy cows to evaluate passage rate, rate of particle breakdown, and digestion. Cows were fed a mixture of bromegrass, timothy, and alfalfa hay with 63% neutral detergent fiber (NDF) and 11.2 % crude protein (CP). The percentage of large particles increased linearly in rumen and duodenum as DMI increased.

Protein

Protein in the diet and its effect on intake has been well documented. (Köster et al., 1996; Heldt et al., 1999; Bandyk et al., 2001). The influence of protein availability and degradability on feed or forage intake has been thoroughly studied. Numerous reviews are available summarizing the plethora of publications documenting the impact of protein supplementation to beef cattle consuming forages with low protein concentration (McCollum and Horn, 1990; Caton and Dhuyvetter, 1997; Moore et al., 1999). Typically, when diets are severely deficient in crude protein (less than seven percent) feed intake decreases (McCollum and Horn, 1990; Moore et al., 1995). In a review of ruminant protein nutrition by Owens et al. (2014), DMI tended to increase linearly as the concentration of dietary crude protein concentration increased. Hayirli et al. (2002) reported that DMI decreased linearly and increased quadratically with increasing dietary rumen undegradable protein.

Diet digestibility and passage rate is decreased if the nitrogen requirements for rumen bacteria are not met (VanSoest, 1982). Galyean and Tedeschi (2014) reported a strong relationship between microbial protein yield (MCP) and daily total digestible nutrient (TDN) intake. Using this concept, the NASEM (2016) beef cattle committee used data from 285 treatment means representing 66 experiments to develop equations predicting microbial protein yield:

$$MCP = 0.087\ TDNI + 42.73,$$

$$MCP = 0.096\ FFTDNI + 53.33$$

where MCP is microbial crude protein, g/d; TDNI is TDN intake, g/d; and FFTDNI is fat-free TDNI, g/d. Microbial protein yield is then assumed to equal the daily RDP requirement needed to optimize feed intake and digestibility. Microbial protein generally supplies 50 to 100 percent of the metabolizable protein (MP) requirement of beef cattle (NASEM, 2016). There are some situations where rumen-undegradable protein (RUP) supplementation may further enhance animal performance. For example, two-year-old lactating heifers that are still growing and have high genetic capacity for milk production may benefit from supplemental RUP beyond the MP provided by microbial protein (NRC 2000). Throughout the remainder of this review, adequate RDP and MP protein supply are considered a prerequisite for the inclusion of experiments or data to evaluate the influence of various other factors influencing feed intake of beef cows. Bodine and Purvis (2003) found it is important to balance protein and TDN on low quality grazing forages.

Processing and particle size

Often processing forage is needed to make feeding forage easier in a dry lot setting. Generally, a liquid such as water or molasses is added to the processed forage to reduce dust and increase palatability. There are mixed results in the literature related to the influence of forage processing on DMI of forages. Yang (2001) found that lactating dairy cows fed higher forage to concentrate ratio diets spent 15.9 percent more time eating and 18.6 percent more time ruminating than cows fed lower forage 8 diets. Decreased particle size decreased time spent eating however the forage particle length did not affect the dry matter intake. Similarly, Finkins (1986), found that organic matter intake of steers eating chopped or ground ammoniated prairie hay was not affected by processing. Contrary to the previous studies, Jaster and Murphy (1983) conducted a study of three treatments, long stem, coarsely chopped, and finely chopped alfalfa hay. Digestibility decreased when consuming chopped hay compared to long stem hay ($P<0.03$). They found that intake was greater when heifers were offered either coarse or finely chopped hay compared to long stem hay (8.45 kg, 8.0 kg). However, there was no statistical difference in DMI between the two chopped hay forms. They concluded that reducing particle size by processing forage increased both DM intake and rate of passage through the rumen while decreasing digestibility.

Animal factors influencing forage intake in beef cows

The root of feed intake comes from the energy requirements of the animal. Energy requirements for cows are based on maintenance requirements and recovered energy. Maintenance has been defined as the feed energy required for zero body energy change (Ferrell and Jenkins 1985). Ferrell and Jenkins et al. (1985) reported that 70 to 75 percent of total annual energy requirements are needed for maintenance. Recovered energy is classified as conceptus, milk, tissue, and activity energy (Freetly et al., 2019). Physiological demand determines how much energy cows need during each stage. Freetly et al. (2019) suggested that the energy a cow needs for each physiological function averaged about 15 percent for milk synthesis, eight percent for conceptus growth, 13 percent for activity, and 64 percent for maintenance.

Mature size and body weight.

It is understood that cow BW directly impacts DMI. According to Long et al. (1975), smaller cows allowed an increased stocking rate for each pasture or dry lot than medium and large cows due to smaller nutrient requirements. Walker (2015) collected individual DMI of beef cows eating hay diets. Lactating cows were fed bermuda grass hay and ryegrass baleage while nonlactating cows were fed ryegrass hay. During the lactating period, cows were blocked by light (544, kg) and heavy (621, kg) cows. The authors reported DMI was eight percent greater (P=0.03) for heavier cows (16.7, kg/d) than the lighter BW cows (15.9, kg/d). In a recent study, cows selected to the heavy BW treatment group consumed more DM annually than those of the moderate BW treatment group (4380 vs. 4113 kg; $P = 0.01$) (Mourer, 2012).

Body Composition

Feed intake can be affected by body composition, especially the percentage of body fat of the animal (NRC 2000). It has been proposed that animals have feedback mechanisms that may regulate intake based on the amount of adipose content of the body (Kennedy, 1953). The lipostatic theory is a thought that hypothalamic control is regulated by a lipostatic mechanism to prevent excessive fat storage. Leptin is secreted by adipose tissue and as adipose tissue increases leptin production increases satiety signals (Illius and Jessop, 1996). According to Fox et al. (1988), when body fat is over the range of 21.3 to 31.5 percent, DMI decreased by 1.7 for each one percent increase in fat. Bines et al., (1969) conducted a cross over study of nonpregnant, nonlactating Holstein cows. Thin (433, kg) and fat (610, kg) cows were each fed a separate diet. The three ad-libitum diets consisted of oat straw, ryegrass hay, and ryegrass hay with concentrates. They found intakes of fat and thin cows were similar eating straw but the fat cows ate less hay and concentrate than thin cows. The authors suggested that the intake of hay might have been limited by ruminal capacity which in turn may have been influenced by the degree of fat.

Stage of Production

An animal's physiological state can considerably influence feed intake. Several published literature reviews evaluating differences in feed intake during lactation compared to gestating or open cows are available. Gestating cows have an increased energy requirement. Due to the conceptus, they require more energy than nonpregnant, nonlactating (open) cows (Freetly et al., 2019). Johnson et al. (2003) evaluated the intake of cows at different stages of gestation and lactation. They found that forage intake significantly differed ($P < 0.0001$) between cows in late gestation, early lactation, and late lactation. Forage intake was 44 and 22 percent greater during lactation compared with late gestation ($P < 0.01$).

It has been reported that lactating animals can increase feed intake by 35 to 50 percent compared with that of nonlactating animals of the same BW and fed the same diet (Agricultural Research Council, 1980). Minson (1990) reported a similar increase in DMI of 30 percent during lactation. Several reports suggest that beef cows in postpartum, increased energy intake corresponded with increased milk production (Perry et al., 1991; Jenkins and Ferrell, 1992; Marston et al., 1995; Lalman et al., 2000). The NRC (1987) suggests that DMI increases by 0.2 kg for each kg of fat-corrected milk. This adjustment was based on data from Mertens et al., (1985) of intake prediction of dairy cows.

(National Research Council, 1978; Agricultural Research Council, 1976. DMI decreased approximately 18 percent as cows progressed from early to late lactation (Johnson et al 2003)

Age

Freetly et al., (2020) found that feed intake is heritable and genetically correlated between heifers and cows and suggests selecting for lower feed intake in growing animals will have the same effects on mature cows. Andresen et al., (2020) looked at the impacts of cow breed type and age on maintenance requirements, feed energy utilization, and voluntary forage intake. They found no difference in forage intake per unit of metabolic BW or maintenance requirements due to cow age. Similarly, Banta et al., (2008) found no difference in DMI or OM between two-year-old, three-year-old and mature cows. Furthermore, Johnson et al. (2003) collected forage intake on multiparous verses primiparous during late gestation, early lactation, and late lactation. Cows were fed ad libitum, low-quality hay (5.3% CP and 76% NDF), and supplemented with cottonseed meal supplemented to ensure adequate protein intake. They found no difference in forage intake as a percent of BW between primiparous and multiparous cows during late gestation. These combined results of recent studies suggest that separate DMI prediction equations are not needed.

Environmental Factors

Varying environmental conditions such as daylight and temperature can affect the intake pattern of cattle (Gaylean and Gunter et al., 2016). Cattle tend to consume feed during the daylight so longer photoperiods result in longer cattle feeding periods and potentially increase intake during seasons where daylight is longer (Forbes et al., 1982). Literature shows that intake changes about one and a half to two percent between months with short and long daylight periods (NRC, 1996). Cattle's response to fluctuations from ambient temperature has been studied and published in older research (Reid and Rob et al., 1971). Cold stress has been shown to decrease intake by 47 percent in grazing cattle not adapted to that environment (Adams et al., 1987). Undoubtedly, moisture and wind can enhance the effects of cold stress. Rainfall can decrease intake for a short duration by 10 to 30 percent (Gaylean and Gunter et al., 2016).

Prediction equations and models

Because direct measurements are not available in production settings, predicting beef cow feed intake is a fundamental aspect of monitoring and balancing nutrient supply in beef cow production systems. However, predicting feed intake of beef cows is a complex and difficult task. Various prediction equations have been published to assist in predicting DMI. As beef cattle nutrition knowledge and technology improves, additional factors should be incorporated into these prediction models to improve prediction precision and accuracy (Ferrell et al., 2008).

The NRC committee developed and published a model for predicting cow intake in the 6^{th} edition NRC (1987) publication. The equation uses components of cow body weight and energy of the diet to predict intake for net energy for maintenance (NEm) of pregnant and nonpregnant cows. For lactating beef cows, the equation suggests multiplying estimated kilograms of milk production by 0.2 to adjust for increased intake.

Coleman et al. (2014) has criticized the NRC equation for poorly predicting cow DMI due to lack of detail included in the model specifically for grazing animals. They put together a large database of pasture and confinement studies with data from growing, nonlactating, and lactating cattle. Coleman et al. (2014) suggested that separate models should be created for growing cattle, gestating cows, and lactating cows.

Bandyk et al. (1998) compiled a database to examine factors influencing feed intake and thus, dependent variables that should be considered in feed intake prediction models. The data set was comprised of 240 treatment means of growing cattle. The dietary CP ranged from 1.9 to 27.8 percent and NDF from 42 to 82 percent. They found that an equation that included forage quality components such as CP, ADF, and NDF were most useful but did not explain much of the variation (R^2=0.41). When including more variables such as ADF: CP ratio the R^2 increased to 60 percent. Although these authors expressed concern about the ability of these relationships to accurately estimate feed intake, they were able to identify some important characteristics to predict intake, including forage crude protein and levels of ADF.

Summary

Many factors affect feed intake in cattle. These diverse factors complicate prediction of DMI. There is limited feed intake data collected for specifically beef cows. Having reliable prediction models to assist in estimating dry matter intake is beneficial to estimate intake and energy requirements. The end goal of cow-calf producers is to make a profit. Historically, a vast amount of focus in the beef industry is put on increasing outputs more so than reducing inputs and associated costs. With feed costs making up more than two-thirds of the total cost to run a cow-calf operation, even small steps to lowering inputs would have a great impact on profitability (Meyer et al 2008).

CHAPTER II

PREDICTING FEED INTAKE IN GESTATING AND LACTACTING BEEF COWS

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ABSTRACT: In 1996, the NASEM beef cattle committee developed and published an equation to estimate cow feed intake using results from studies conducted or published between 1979 and 1993. The same equation was recommended for use in the most recent version of this publication in 2016. The equation utilizes body weight (BW), diet digestibility and milk yield. Our objective was to validate the accuracy of the NASEM equation using recently published and unpublished data. Criteria for inclusion in the validation data set included projects conducted or published since 2002, direct measurement of forage intake, adequate protein supply, and pen feeding (no tie stall or metabolism crate data). The validation data set included 48 treatment means for nonlactating cows and 29 treatment means for lactating cows. Quantitative data collected for the nonlactating data set included BW (593 ± 78.1 kg), BCS (5.7 ± 0.73), and Mcal NEm per kg of feed (1.26 ± 0.16 Mcal/kg) and lactating data set included DMI (12.7 ± 2.98 kg) and BW (505 ± 62.4 kg), BCS (4.6 ± 0.44), NEm per kg feed (1.25 ± 0.24 Mcal), and DMI (14.3 ± 2.08 kg), respectively. Non-intercept models were used to determine slope and bias when predicted DMI was regressed against observed DMI. The slope for linear bias in the NASEM nonlactating equation differed from 1 ($P = < 0.0001$) with a 13.9 percent downward bias. Similarly, when the NASEM equation was used to predict DMI in lactating cows, the slope differed from 1 ($P < 0.0001$) with a downward bias of 16.6 percent. Therefore, new prediction models were developed for both

nonlactating and lactating cows. Log and exponential transformations were used to correct for heteroskedasticity. The best-fit nonlactating and lactating equations seem to provide need to be further validated with independent data sets. The current NASEM equation for predicting intake underestimated feed intake for both gestating and lactating

beef cows. The new equation may improve the accuracy of predicting cow feed or forage consumption.

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 have been 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 (Galyean and Gunter, 2016; Lalman et al. 2019; NRC 2001). 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 Research Council (NRC) 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 necessarily 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 animal 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 validate beef cow feed intake prediction equations using more recent data limited to direct measurement approaches.

MATERIALS AND METHODS

Data Collection

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 our own laboratory at the Range Cow Research Center, Oklahoma State University. The first screening criteria imposed was to include only data sets 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 data from experiments conducted or published between 1979 and 1993. Therefore, in an effort to avoid data sets used in that previous analysis, search criteria were established to restrict inclusion to projects conducted or published between 2003 and 2020. 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, to be considered for inclusion, treatment (or period) means must have been a result of direct measurement of feed or forage intake; no data generated from marker-based methodology were included. Intake from marker data was not used in order to avoid any errors or challenges associated with this method such as incomplete marker recover and dosing challenges (Cordova et al., 1978). Coleman (2014) states alkanes could overestimate digestibility and therefore result in a higher estimated intake. Predicting diet quality is very difficult in grazing settings due to selectivity (Langlands et al., 1974 and Holechek et al., 1982). Coleman (2014) stated that direct measurements of intake must be considered the gold standard for accuracy. Concerns of changes of normal behavior and grazing activity is associated with dry lot intake data. The intake of dry lot animals does not consider energy expenditure required for grazing and may underestimate feed intake (Coleman et al., 2014).

Only data from experiments identified as having provided adequate protein supply to meet ruminal and animal requirements were included. Finally, experiments using tie stall or metabolism crate housing were excluded from the data set. Available data sets utilized predominantly Bos taurus cattle with British or British/Continental breed influence.

A summary of the qualitative data collected for the analysis is provided in Table 1 and Table 2. Treatment or period mean was considered to be the experimental unit with each study containing between one and five means. Data extracted from the papers included general information: author name, source, date of publication, treatment, processing of forage, stage of production and milk yield collection method, when applicable. The qualitative details included cow BW, body condition score (BCS), DMI, SE of DMI, forage total digestible nutrients (TDN), supplement intake, supplement TDN and milk yield when applicable. Reported diet NEm was used or calculated from TDN according to the NASEM (2016) system. When diet energy values were not provided, ingredient tabular nutritive values were used to calculate NEm. Treatment or period mean, standard deviation, minimum and maximum values for each data set are shown in Table 3. Quantitative and qualitative data from each source was organized into two tables in Microsoft Excel, one for gestation and one for lactation. In cases where supplement was provided, the contribution of supplement to daily DMI and NEm was included. Therefore, observed daily DMI and observed daily NEm intake represents the sum of contributions from the basal diet plus supplement.

Calculations and Statistical *Analysis*

A total of 81 (53 gestating and 29 lactating) treatment means met the screening criteria. Within each data set, observations were further evaluated for outliers. Outliers were determined using residuals calculated by regressing Kcal NE_m intake / kg $BW^{0.75}$ on diet NEm (Mcal/kg) and subsequently subjected to a studentized residuals test. An outlier was defined when an observation had a studentized residual that was larger than 3 (in absolute value) (SAS Inst. Inc., Cary, NC). In one experiment, feed intake was measured for nonlactating, nonpregnant cows first consuming grass hay, then later consuming grass silage (Martin et al., 2019). The mean for grass 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, four treatment means for nonlactating cows met the exclusion criteria due to exceptionally high feed intake relative to diet energy concentration. This was presumed to be due to feeding management through the mid and late-lactation period prior to measurement of voluntary feed intake. In both experiments, cows were limit-fed a high-concentrate diet at a maintenance level of feed intake for a long period of time prior to the voluntary feed intake study. These modifications resulted in the availability of 48 observations for the nonlactating validation data set with a range in diet NEm of 0.93 to 1.54 Mcal NEm.

There were no outliers identified in the lactating cow data set with a range of NEm (Mcal/kg) from 1.0 to 1.77. However, few experiments were available with diet NEm > 1.4 Mcal/kg with 62% < 1.2 Mcal/kg, 24% between 1.2 and 1.4 Mcal NEm and only 14% > 1.4 Mcal/kg (four treatment means from one experiment).

Three prediction equations for gestating cows and three prediction equations for lactating cows were tested against the respective validation data sets: NRC 1987-Eq. A, NRC 1996-Eq. B, and Hibbard and Thrift 1992-Eq. C and D (Table 4). 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 (Dr. T.A. Thrift, personal communication, September 2018). Resulting equations are shown in the footnotes for Table 3.

Linear bias was tested using the PROC REG procedure in SAS (v. 9.4; SAS Inst. Inc., Cary, NC). Non-intercept models were used where the y (predicted values) were regressed against x (observed intake values) to determine if the slope of the regression differed from one using an F-test ($P < 0.05$). Percent bias was determined by subtracting one from the slope and multiplying by 100. RMSE, slope, and percent bias were used to evaluate the fit of the prediction equations.

Model development was conducted using REG and GLIMMIX procedure in SAS (v. 9.4; SAS Inst. Inc., Cary, NC) to predict daily NEm intake (NEmI) expressed as Kcal/kg $BW^{0.75}$ similar to the method of NRC (1996) and NASEM (2016). Variables tested included dummy variables for approximate stage of production and forage processing, milk yield expressed as g/kg $SBW^{0.75}$, BCS, and diet NEm, Mcal/kg. Similarly, prior to model development for lactating cows, milk yield was transformed to g/kg $SBW^{0.75}$. Processing was significant in the model however we excluded processing after realizing that processing methods were not consistent across NEm of the study. On average, the processed diets were also high NEm diets with just a few low NEm studies having processed forage. Of the treatment means utilizing processed forage, 7 of the 50 were considered low quality (< 1.04 NEm) with a majority of diets NEm between 1.12 and 1.77.

Reported standard errors for kg of DMI within each study were used to correct for presence of heteroscedasticity using weighted least squares (WLS). In addition, logarithmic of diet NEm were tested using regression to find the best fit model. Determination variables were excluded when $P > 0.15$ (Bursac et al., 2008). Generalized linear mixed models were also used with exponent transformation of diet NEm. The exponential function is the inverse of the natural logarithm (SAS Inst. Inc., Cary, NC). Log transformation on the left side was used to linearize the coefficients.

RESULTS AND DISCUSSION

Validation of existing equations for nonlactating beef cows

Results from regressing predicted feed intake for dry, gestating and open cows against observed feed intake values are shown in Table 4. Equation A had the lowest root mean square error (RMSE). However, daily feed intake was substantially underestimated by this equation. When observed feed intake was at the low end of the range in diet NEm (Mcal/kg of feed) for the validation data set, Eq. A provided reasonably accurate estimates. However, as observed daily feed intake increased, predictions were increasingly underestimated (by as much as 6 kg at the upper end of observed values; data not shown).

Compared to Eq. A, equations B and C explained less of the variation in observed values with greater RMSE. Nevertheless, Eq. B had lower average bias although daily feed intake was still underestimated ($P \geq 0.0001$). As shown in Fig. 1, Eq. B accurately predicted feed intake when observed values were less than 13 kg while underestimating daily feed intake in situations resulting in greater than 13 kg DMI. Conversely, on average, Eq. C overpredicted ($P \geq 0.0001$) feed intake with a bias of 14.0%. More specifically, feed intake was overpredicted with observed values below the mean in the validation data set and underestimated in situations where observed values were at the upper end of the range (data not shown).

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, thirty-five 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 et al., 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 validation 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 used to predict feed intake in this more recent validation data set.

Validation of existing equations for lactating beef cows

When predicted values were regressed on observed DMI values for lactating cows, the slope of the regression line differed from one ($P \geq 0.0001$) in all three equations (Table 4) with a negative bias. While equations A and B explained a greater proportion of the variation in observed values, they underestimated feed intake to a greater extent (-26 and -17%, respectively) compared to Eq. D at (-4.7%). However, RMSE was greater for Eq. D than the other two signifying the residuals were less concentrated around the line of best fit.

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 one 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 validation results should be reflected in the lactating cow validation results because the same equations 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. Moreover, based on data from Coleman et al., (2014) and Johnson et al., (2003), Lalman et al., (2019) suggested the coefficient for the influence of milk on feed intake should be increased and may fall within the range of 0.33 to 0.55 kg DMI/kg milk yield.

Model development for nonlactating beef cows

With considerable lack of fit in existing equations, the validation data set was used to develop new prediction equations. Subsequently, equations were developed predicting NEm intake, Kcal/kg $BW^{0.75}$. Because NEm intake is scaled to $BW^{0.75}$, cow BW is not included in the model development step.

A review by Ingvartsen (1992) shows that during the last 8 weeks of gestation, intake decreases by 2.7% per week as rumen capacity decreases with increased fetus growth. The dummy variables for stage of gestation and processing were included in the initial steps of model development for both gestating and lactating cows. However, neither stage of production nor processing explained a significant amount of the variation for daily DMI and are therefore were not included in the final models (Table 5). Perhaps the lack of significance for the stage of gestation variable is not surprising given that "early" and "late" gestation are generalizations for a group of animals with variable breeding and calving dates. Similarly, this data is not ideal to determine the influence of diet processing on feed intake.

The plot of the data appeared to be exponential (Figure 3), as intake increased also did diet NEm. Heteroskedasticity was detected ($P < 0.01$) with increasing variance as diet NEm increased. Therefore, logarithmic and exponent transformations for diet NEm, Mcal/kg $BW^{0.75}$ were evaluated (Table 5). Given that intake is influenced by diet energy, an intake (NEm $BW^{0.75}$) model was estimated using the REG and GLIMMIX procedure in SAS (v. 9.4; SAS Inst. Inc., Cary, NC):

$$\text{NEmI} = \beta_0 + \beta_1 \text{Ln(NEm)} + ei + vi \qquad \text{[Eq. 1-a]}$$

$$\text{NEmI} = \beta_0 + \beta_1 \text{NEm} + ei + vi \qquad \text{[Eq. 1-b]}$$

Predicted daily feed DMI (kg/d) is then calculated by dividing NEm intake, Kcal/kg $BW^{0.75}$ by diet NEm, Mcal/kg. The new equation's and equation A, B and C 's prediction of nonlactating cow feed intake (kg/d) relative to diet NEm (Mcal/kg) is shown in Figure 4.

Model development for lactating beef cows

The increase in maintenance energy requirement related to the added metabolic activity associated with lactation has been reported to range from 5% (Wiseman et al., 2019) to 38% (Neville et al., 1974). A wide range in escalated maintenance associated with lactation could account for at least some of the unexplained variation associated with lactating cow feed intake. For this reason and the substantial underprediction of Eq. A and B for lactating cows, a separate model development process was undertaken for lactating cows.

Johnson (2003) found that DMI decreased approximately 18% as cows progressed from early to late lactation. However, like the nonlactating cow data set, neither stage of lactation nor feed processing dummy variables explained enough variation in DMI to be incorporated into the prediction equations. Diet NEm explained the majority of the variation in observed DMI ($R^2 = 0.89$) and milk yield.

Two models predicting feed intake for lactating cows are also provided in Table 5. The model for lactating cows, expressed as total NEm intake (Kcal/kg $BW^{0.75}$):

$$\text{NEmI} = \beta 0 + \beta 1\text{NEm} + \beta 2\text{Milk yield, kg}\ BW^{0.75} + ei + vi \qquad \text{[Eq. L-1]}$$

The linear term for milk yield was significant at $P = 0.016$. This relationship is equal to 0.34 kg increase in feed intake per kg increase in milk yield when cows consume a 1.3 Mcal/kg diet. This is similar to the results of Johnson et al. (2003), who reported 0.33 and 0.37 kg increased feed intake per kg increased milk yield. However, Coleman et al. (2014), using a meta-analysis approach, estimated 0.55 kg increased feed intake per kg increased milk yield.

This approach to determine the relationship of feed intake to milk yield is not ideal, in part, due to different milk yield measurement techniques. For example, in the current validation data set, seven of the twelve studies employed the weigh-suckle-weigh (WSW) milk yield measurement technique while five studies utilized a machine milking protocol. Expressed as g milk / kg $BW^{0.75}$, milk yield averaged 52 and 75 for WSW and machine milking, respectively. It is not possible to distinguish between differences among studies in true milk yield versus potential differences in estimates of milk yield due to the method employed. A more reliable estimate of the influence of milk yield on feed intake would be to summarize within-experiment regression coefficients.

Figure 5 demonstrates the relationship between observed DMI (Kcal/kg BW^0.75) and diet NEm (Mcal/kg of feed) of lactating beef cows. There appears to be a fairly strong linearly relationship of diets between 1.0 and 1.4.

Validation of New Models

Three data sets were used to validate equations 1-a and 1-b (H. Freetly, personal communication, 2020). A total of 1,681 individual feed intake data points from nonlactating (pregnant and open) beef cows fed rations ranging in diet NEm from 1.05 to 1.5 Mcal/kg (approximately 52.5 to 65% TDN). Predicted DMI was regressed on observed DMI for both developed gestation equations. Equation 1-a resulted in a 2.2 % bias over prediction and $R^2 = 0.75$. The 1-b exponent equation had a bias of 3.6 % with a $R^2 = 0.71$. Based on these results, both equations provide reasonable estimates of average feed intake in nonlactating beef cows. Additional independent data sets with a wider range in diet energy content should be used to further validate equations 1-a and 1-b.

Independent feed intake data was not available for the validation of the lactating cow equation (L-1). Previously, NRC (1996) recommended use of the gestation equation Eq. B adjusted for lactating cows using a linear coefficient for milk yield. Therefore, this approach was tested using Eq. 1-a and 1-b incorporating the NRC (1996) coefficient for milk yield (0.2 kg DMI / kg milk yield; Eq. 2-a and 2-b). Additionally, the lactation coefficient adjustment reported in Table 5 (0.34 kg DMI/kg milk yield; Eq. 3-a and 3-b). These prediction equations were tested using the 29 lactating treatment means using the same regression procedure.

Neither gestation equation with the added lactation factors provided accurate estimates of DMI for lactating beef cows. Both 2-a and 3-a prediction equations with the NRC lactation factor under predicted intake when compared to observed intake (-13.1, -11.0, respectively). The RMSE for each prediction over observed intake was 1.2 and 1.8, respectively. Prediction equations 3-a and 3-b with a factor for lactation of 0.34 kg increased intake for each kg increase of milk yield was applied to predicted intake and regressed over observed intake. The percent bias was 8.7 and 10.8 with an RMSE of 1.7 and 2.4. We conclude that the new gestation equations, adjusted for lactation using a linear coefficient for milk yield is not an acceptable approach. Until further equation development and validation data are available, the L-1 equation should be used to estimate DMI in lactating cows.

CONCLUSION

Previously published equations (NRC, 1987 and NRC, 1996) underestimated feed intake. New models were developed using nonlactating and lactating intake data.

Validation of the nonlactating models show that these models might be better predictors than current models. We acknowledge that the data sets used to create the models was relatively small. Therefore, these new prediction models should be tested on independent data sets to validate their accuracy of predicting DMI in beef cows. Although prediction equations are useful tools, no prediction model will fit every scenario. The newly nonlactating and lactating equations are both worthwhile and acceptable in predicting intake of beef cows.

Table 1. Summary of data sources for feed intake of gestating beef cows

First Author, Year	Source[1]	No. of treatment means	Forage Processing	Stage
Banta, 2008	J	5	Long Stem	Mid/Late Gestation
Cassaday, 2016	T	4	Processed	Mid Gestation
Freetly, 2019	T	3	Processed	Mid/Late Gestation
Gross, 2019	T	1	Long Stem	Mid Gestation
Holder, 2018	T	1	Long Stem	Late Gestation
Holder, 2019	T	2	Processed	Mid Gestation
Holder, 2019	T	2	Processed	Mid Gestation
Holder, 2020	T	2	Long Stem	Late Gestation
Holder, 2020	T	2	Processed	Late Gestation
Jarstedt, 2018	J	2	Processed	Open
Johnson, 2003	J	4	Long Stem	Late Gestation
Kennedy, 2016	J	1	Processed	Late Gestation
Lalman, 2017	T	2	Long Stem	Mid Gestation
Martin, 2019	J	1	Processed	Mid Gestation
Moehlenpah, 2019	T	5	Processed	Open
Mourer, 2010	T	2	Long Stem	Mid/Late Gestation
Sexten, 2013	T	4	Long Stem	Late Gestation
Walker, 2015	J	2	Processed	Mid/Late Gestation
Warren, 2017	J	3	Processed	Mid/Late Gestation

[1] Source code refers to as: J = journal, T = thesis or abstract.

Table 2. Summary of data sources for feed intake of lactating beef cows

First Author, Year	Source[a]	No. of treatments	Forage Processing	Stage	Milk Procedure[b]
Black, 2013	J	3	Processed	Mid Lactation	WSW
Cassaday, 2016	T	2	Processed	Early Lactation	WSW
Gross, 2019	T	1	Long Stem	Mid Lactation	Machine
Gross, 2020	T	1	Long Stem	Mid Lactation	Machine
Holder, 2019	T	1	Long Stem	Mid Lactation	Machine
Johnson, 2003	J	4	Long Stem	Early Lactation	Machine
Johnson, 2003	J	4	Long Stem	Late Lactation	Machine
Mourer, 2012	T	2	Long Stem	Early Lactation	WSW
Mourer, 2012	T	2	Long Stem	Late Lactation	WSW
Walker, 2015	J	2	Processed	Mid Lactation	WSW
Williams, 2018	T	4	Pelleted	Early Lactation	WSW
Winterholler, 2009	J	3	Long Stem	Early Lactation	WSW

[a] Source code refers to as: J = journal, T = thesis or abstract.
[b] Milking procedure is identified as either weigh-suckle-weigh or machine.

Table 3. Mean, standard deviation, minimum and maximum for observed variables

Item	Number of treatment means	Mean	STD	Min	Max
Nonlactating	48				
Cow BW, kg		593	78.1	403	700
BCS		5.7	0.73	4.4	7.5
DMI, kg		12.7	2.98	8.3	20.6
Diet NEm, Mcal/kg[a]		1.26	0.16	0.93	1.54
Lactating	29				
Cow BW, kg		505	62.4	403	611
BCW		4.7	0.44	4.1	5.7
DMI, kg		14.3	2.08	10.3	19.2
Diet NEm, Mcal/kg[a]		1.25	0.24	1.00	1.77
Milk yield, kg		6.42	2.23	3.00	11.3

[a]Mcal = megacalories of net energy for maintenance per kg of feed.

Table 4. Results of regressing predicted dry matter intake on observed dry matter intake for three equations.

	Equation	RMSE[a]	Bias, %[b]	*P*-value[c]
Gestation				
	Eq. A (NRC 1987)[d]	1.44	-18.8	$P < 0.0001$
	Eq. B (NRC 1996)[e]	1.97	-8.4	$P < 0.0001$
	Eq. C (Hibberd and Thrift, 1992)[f]	2.26	14.0	$P < 0.0001$
Lactation				
	Eq. A (NRC 1987)[d, h]	0.87	-26.0	$P < 0.0001$
	Eq. B (NRC 1996)[e, h]	0.77	-17.3	$P < 0.0001$
	Eq. D (Hibberd and Thrift, 1992)[g]	1.27	-4.3	$P < 0.0001$

[a] RMSE = root square mean error.
[b] Bias is calculated as the observed slope minus 1.0 multiplied by 100.
[c] P-value represents the probability the slope differs from 1.0.
[d] Eq. A: DMI, kg / d = $SBW^{0.75}$, kg * (0.0194 + 0.0545 * NE_m).
[e] Eq. B: DMI, kg / d = $SBW^{0.75}$, kg * (0.04997 * NE_m^2 + 0.04631) / Feed NEm, Mcal/kg.
[f] Eq. C: DMI, kg / d = (-0.0323 * NEm^2) + (0.0944 * NEm) - 0.0418 * SBW, kg.
[g] Eq. D: DMI, kg / d = (-0.0261 * NEm^2) + (0.07777 * NEm) - 0.0277 * SBW, kg.
[h] Gestation equation with added lactation factor (0.2 kg*kg of milk yield).

Table 5. Regression equations predicting daily NEm intake, Kcal/kg $BW^{0.75}$

	Parameter estimates				
Item	Intercept	NEm[a]	Milk	Log NEm	Exp NEm[b]
Gestation					
1-a[b]	0.0739***	-	-	0.2903***	
1-b[c]	2.9126**	-	-	-	1.5551*
Lactation					
L-1[d]	-125.08***	214.71***	0.4354**	-	-

[a]NEm, Kcal/kg = net energy for maintenance.
[b]The logarithmic transformation model: NEm intake, Kcal/kg $BW^{0.75}$ = 0.0739 + Ln (NEm) * 0.2903.
[c]The exponent transformation model: NEm intake, Kcal/kg $BW^{0.75}$ = exp (2.9126 + 1.5551 * NEm).
[d]Multiple regression model for lactating cows:
NEm intake, Kcal/kg $BW^{0.75}$ = (214.71 * NEm, Mcal/kg) + (0.4354 * g milk/kg $BW^{0.75}$) – 125.08.
[*]Accounts for significance of variation explained by the model component ($P < 0.1$).
[**]Accounts for significance of variation explained by the model component ($P < 0.05$).
[***]Accounts for significance of variation explained by the model component ($P < 0.0001$).

Table 6. Results of regressing predicted dry matter intake on observed dry matter intake for three equations.

Equation		RMSE[a]	R^2	Bias, %[b]	*P*-value[c]
Gestation					
	Eq. 1-a LOG	1.41	0.748	2.2	P < 0.0001
	Eq. 1-b EXP	1.42	0.712	3.6	P < 0.0001
Lactation					
	Eq. 2-a LOG NRC	1.2	0.81	-13.1	P < 0.0001
	Eq. 3-a LOG GROSS	1.7	0.78	8.7	P < 0.0001
	Eq. 2-b EXP NRC	1.8	0.71	-11.0	P < 0.0001
	Eq. 3-b EXP GROSS	2.4	0.68	10.8	P < 0.0001

[a] RMSE = same as root square mean error.
[b] Bias is calculated as the observed slope minus 1.0 multiplied by 100.
[c] P-value represents the probability the slope differs from 1.0.

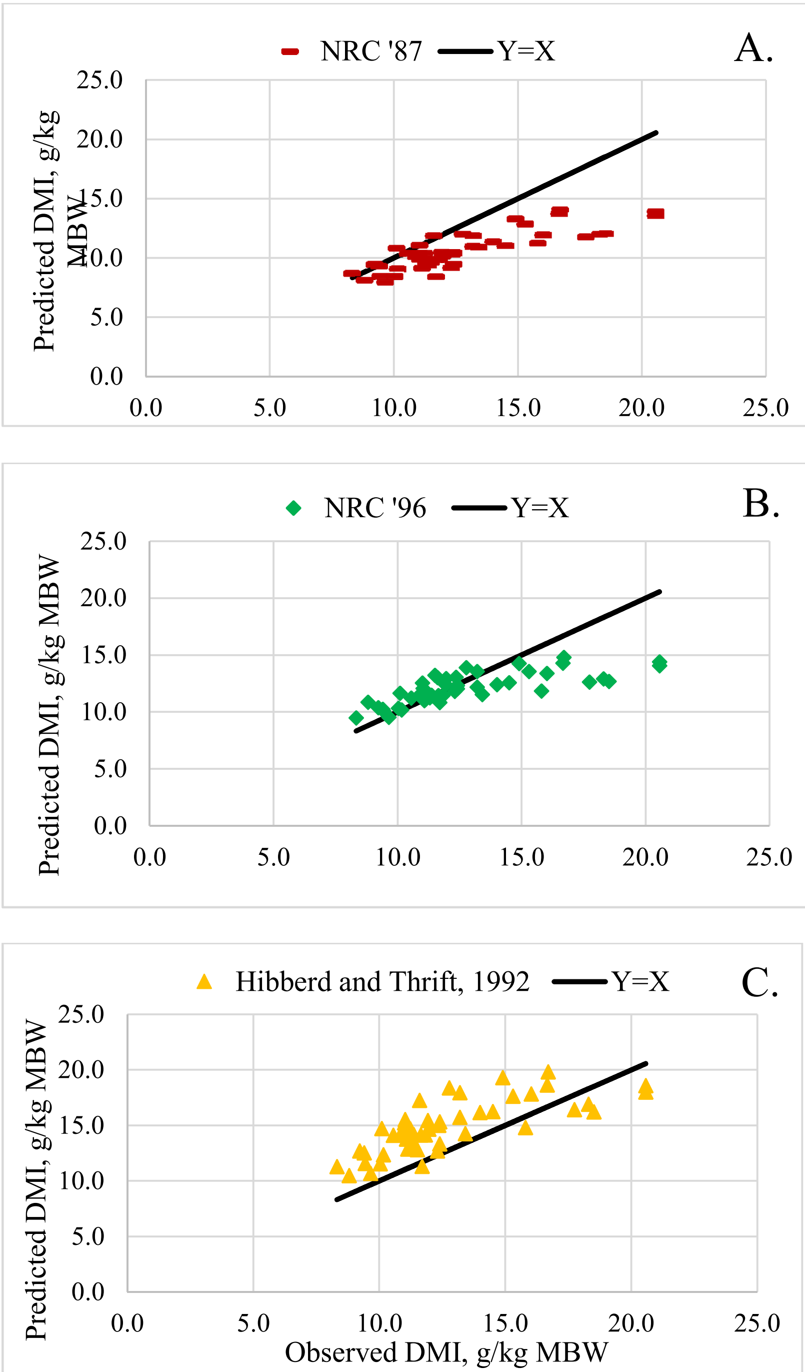

Figure 1. Relationship of 48 gestating cow feed intake means, kg/d to predicted feed intake, kg/d using Eq. A (NRC 1987), Eq. B (NRC 1996), and Eq. C (Hibberd and Thrift, 1992). bias = -8.4).

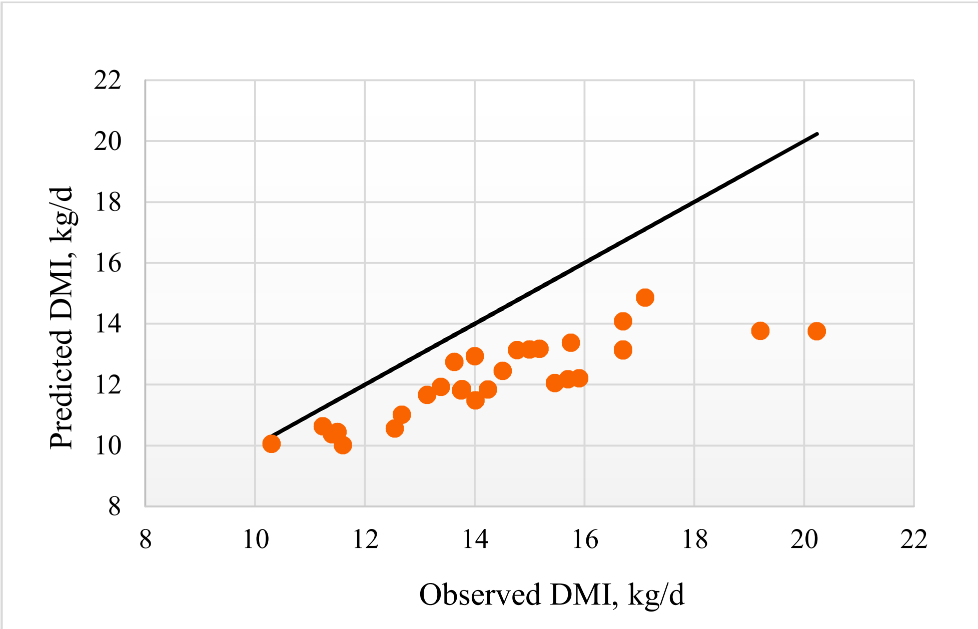

Figure 2. Relationship of 29 lactating cow feed intake means, kg/d to predicted feed intake, kg/d using Eq. B plus 0.2 kg DMI per kg milk yield (NRC, 1996) ($R^2 = 0.75$, % bias = -17.3).

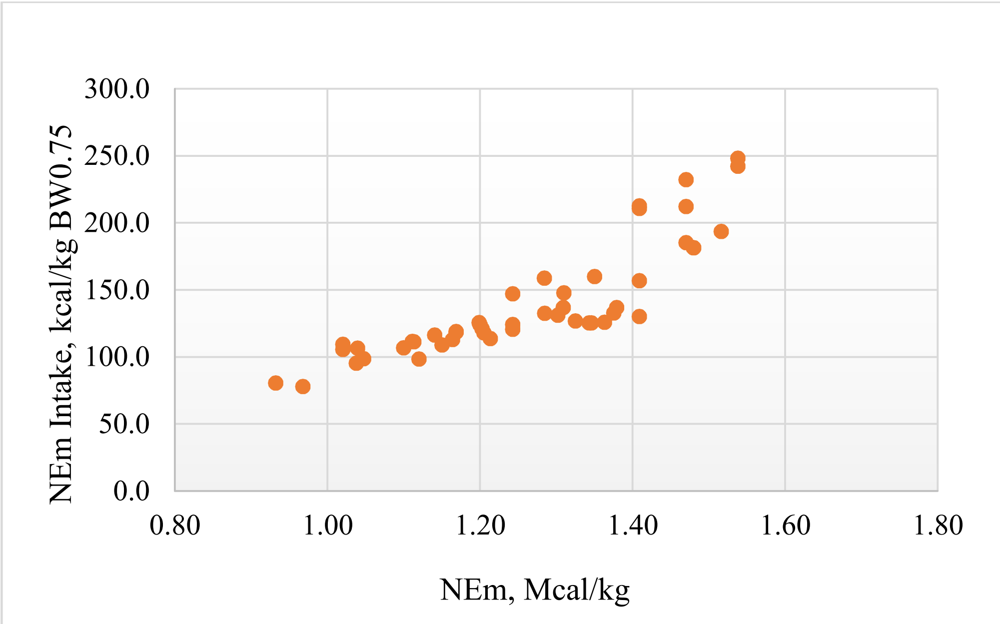

Figure 3. Relationship of diet NEm, Mcal/kg to NEm intake, kcal/kg $BW^{0.75}$ in nonlactating beef cows.

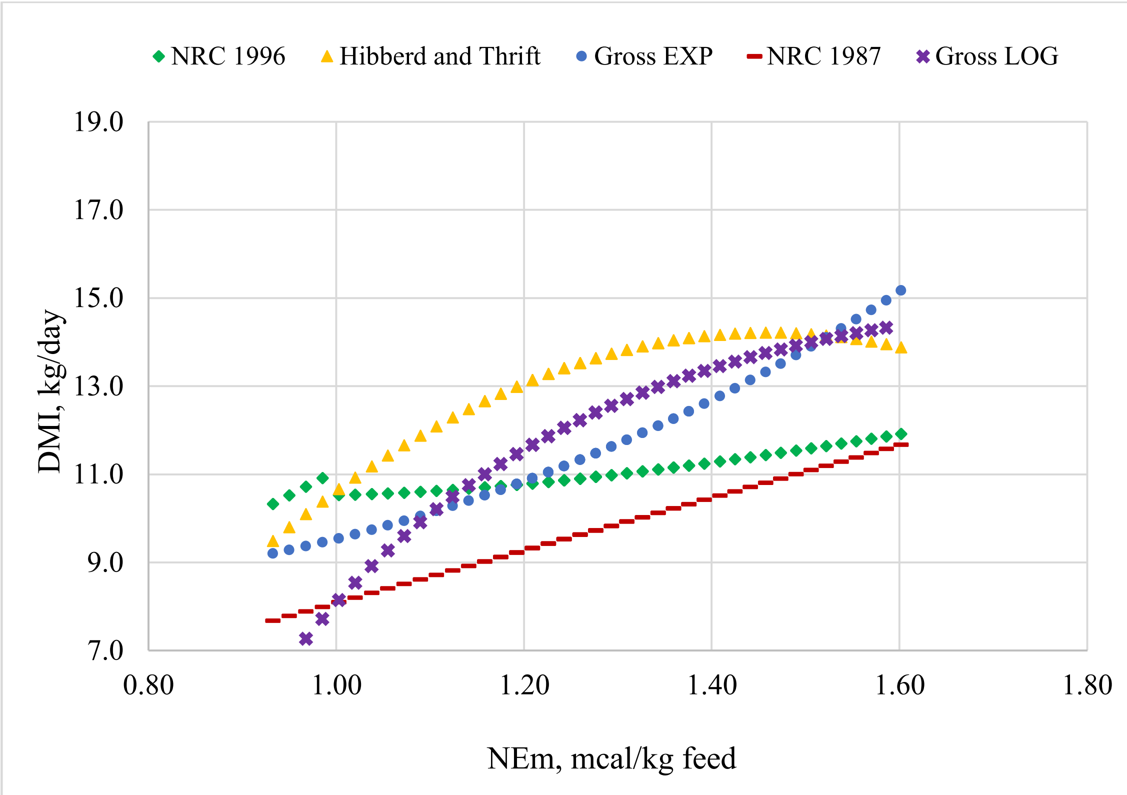

Figure 4. Predicted feed intake for 545 kg nonlactating beef cows (closed diamonds = NASEM, 2016 equations 19-95 and 19-96; dashed line = NRC 1987; closed triangles, Hibberd and Thrift, 1992; closed x = new equation Log, 1-a; closed circles = new equation Exp, 1-b).

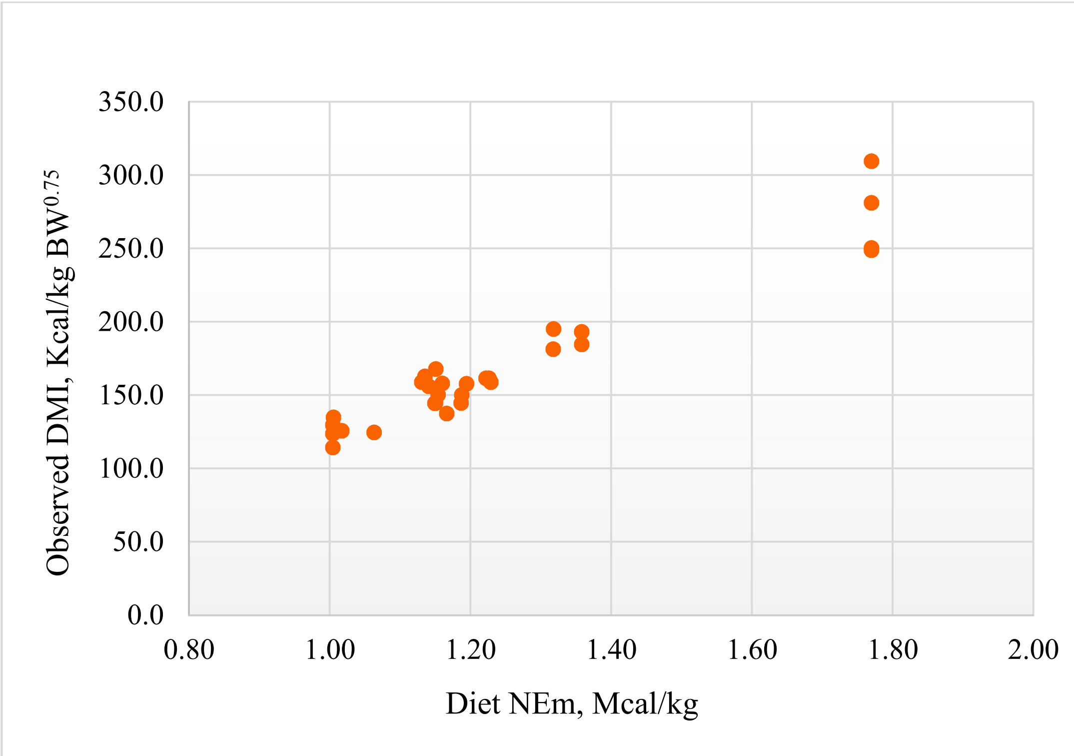

Figure 5. Relationship of diet NEm, Mcal/kg to NEm intake, kcal/kg $BW^{0.75}$ in lactating beef cows.

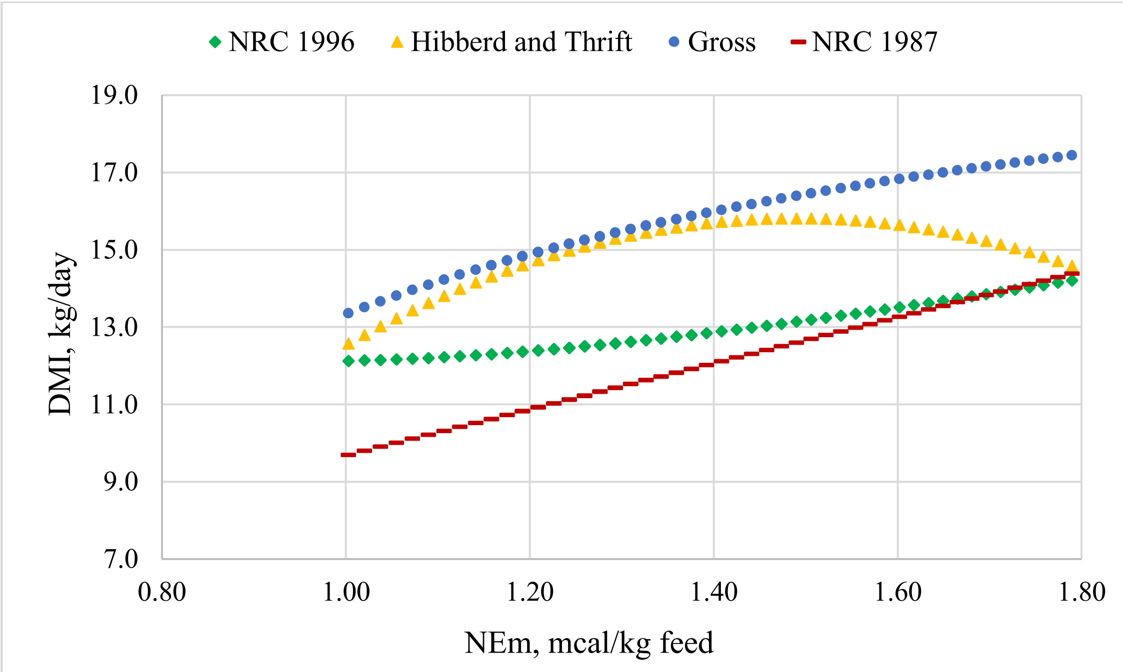

Figure 6. Predicted feed intake for 545 kg beef cows producing 8 kg milk/d (closed diamonds = NASEM, 2016 equations 19-95 and 19-96; dashed line = NRC 1987; closed triangles, Hibberd and Thrift, 1992; closed circles = new equation, L-1).

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