Predicting Forage Intake by Grazing Beef Cows[2]

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Introduction

The control of feed intake by ruminants is complex, and developing a cohesive theory of intake control in ruminants continues to be a challenge. Because our understanding of factors that regulate intake by cattle is inadequate, predicting feed intake, even under the best of circumstances, is difficult. In grazing cattle, this difficulty is exacerbated by additional influences that can sway basic control mechanisms, including selective grazing, herbage mass, sward structure and composition, climatic and environmental factors, and the intricacies of the grazing process itself.

The sheer complexity of intake control in ruminants and the associated lack of mechanistic models has led to a reliance on empirical approaches. Fisher (2002) suggested that empirical models, despite their frequent lack of intellectual elegance, have considerable merit leading to many practical applications in beef cattle feeding. Generally, most empirical models in use today are based on the physical/physio-chemical theory of intake regulation. Thus, intake of less digestible, low-energy diets is mostly controlled by physical factors like ruminal fill and digesta passage where intake of highly digestible, high-energy diets is mostly controlled by energy demands of the animal and by metabolic factors (e.g., ruminal acidity and metabolic protein yield; NRC (1985, 1987). Examples of empirical equations that reflect the role of energy concentration in controlling feed intake are those based on body weight (**BW**) and dietary net energy for maintenance (**NEm**) concentration recommended by the NASEM (2016) beef nutrient requirements publication.

Regardless of their composition, empirical equations for predicting intake are far from perfect, typically accounting for only 50 to 70% of the variation in intake, with relatively high standard errors of prediction (5% of the mean or greater) where intake was measured directly. When applied to grazing situations, these equations might yield less than desirable accuracy and precision. In this review, I will summarize some of the factors that affect intake by grazing cattle and current means of predicting intake.

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Factors Affecting Grazed Forage Intake

Factors Affecting Selective Grazing

Total mixed rations (**TMR**) are often used in penned cattle in an effort to provide a uniform supply of nutrients, but sorting of dietary components from TMR is well-documented (Leonardi and Armentano, 2003). Thus, ruminants are inherently driven to select for certain types and sizes of feed components, thereby modifying their nutrient intake relative to the composition of the feed offered. For grazing cattle, the pasture resource is constantly changing. Preferred plant parts from the grazing domain have been removed after a meal, and the pasture has become more or less mature depending on the temporal scale. Hence, grazing cattle potentially have a different forage resource from which to select their diet each day, potentially affecting intake in a variety of ways.

The interaction of cattle with their landscape can be separated into space and time scales. Scale is a required concept in grazing ecology research and model building that would predict voluntary intake, referring primarily to the spatial and temporal dimensions at which cattle are observed (**Figure 1**). For example, estimates of grazed forage intake are often measured in relatively small pastures (e.g. 7 to 49 ha) and for short periods of time (e.g., 5 d; Krysl et al., 1987; Gunter et al., 1997). Nonetheless, data collected at these limited scales are often applied over weeks or months (greater temporal scales) and in extensive grazing environments of much greater spatial scale. More often than not, the empirical models that are used to make management decisions were constructed with cattle that were sensing and processing information at a different spatiotemporal scale than the cattle to which the models are applied. Hence, patterns and processes observed in animal behavior, including forage intake, depend greatly on the scale at which they were studied (Senft et al., 1987).

Differences noted in dietary quality and the voluntary intake by grazing cattle are associated with individual animal preferences and choices. The decisions to eat and which foods to consume are made on the basis of the expected reward and are influenced by past experiences, which then influences the animal’s “wanting” and “liking” for food (Provenza et al., 2015a). Ginane et al. (2015) asserted that wanting, liking, and learning are different aspects of the food-selection process. Wanting is the motivation for the reward, which might be initiated by the internal state of the animal or by external stimuli. Liking is the pleasure component of a reward, which encompasses conscious and unconscious responses. Learning by cattle is associated with a past reward based on experiences. The positive attributes of learning are especially noticeable when new cows are introduced to a novel grassland, which sometimes results in a high percentage of the cows having difficulty maintaining body condition score (**BCS**) compared with experienced cohorts.

Choices of food by cattle span generations and the expression of these choices is influenced during critical periods of fetal development, which can have influences on life-long feeding behaviors. Villalba et al. (2015) showed how experiences in utero and early life can cause physiological changes that alter food preferences and voluntary forage intake later in life. By interacting with the genome during growth and development, environments influence gene expression and behavioral responses (Provenza et al., 2015b). For example, lambs exposed to saltbush (*Atriplex* spp.) in utero, grew faster and handled greater salt loads than lambs gestated in ewes grazing mono-cultures of introduced grasses (Chadwick et al., 2009). Sheep (Distel et al., 1994) and cattle (Wiedmeier et al., 2012) exposed early in life to forages high in fiber had increased nitrogen retention and the ability to digest fiber more completely later in life than cohorts reared in utero on low-fiber diets. Based on these and other experiments, the "absolute value" of a food can change because the ability of animals to utilize forages can be enhanced or diminished by developmental experiences in utero. Hence, each grazer could potentially select a different diet depending on its learned and genetic preferences, a phenomenon that is extremely difficult to empirically model.

Part of the reason for selective grazing is that livestock attempt to maintain a balance between energy and protein in their diets, a balance that is achieved by associating the flavors of foods with nutrient-specific feedbacks. For example, lambs fed diets low in energy or protein preferentially ate non-nutritive flavored food previously associated with the feedback from ruminal infusions of protein or energy, respectively (Villalba and Provenza, 1996). Moreover, lambs chose a diet that would maximize growth when offered isocaloric foods that varied in protein and they ate less protein as they aged, reflecting a decreased requirement (Kyriazakis and Oldham, 1993). Forage intake decreases with imbalances of energy relative to protein and increases with appropriate ratios of energy to protein. When sheep are fed protein- or energy-imbalanced diets, they will then graze in locations with forages that rectify the nutrient imbalances (Scott and Provenza, 2000). In addition, steers (BW = 301 ± 26 kg) grazing a low-protein native prairie and fed 500 g/d of a 32% CP supplement, selected 76% fewer forbs than non-supplemented cattle to maintain a favorable protein to energy balance (Odadi et al., 2013). Thus, ruminants seem to sense dietary protein content and modulate short-term intake of flavored foods, seeking additional protein to balance their protein-to-energy intake ratio, ultimately affecting total voluntary intake.

Effects of ambient temperature on feed intake, digestibility, and rate of passage of pen-fed ruminants have been studied extensively and reviews are available on the subject (Kennedy et al., 1986). Fewer data are available for grazing ruminants, but effects are likely similar between pen-fed and grazing cattle in terms of the physiological consequences of heat and cold stress. In experiments with controlled environmental conditions, it seems clear that feed intake increases when the temperature falls below the lower point of the thermoneutral zone (generally -15 to 28ºC for mature beef cows; FASS, 2010) and decreases as the ambient temperature rises above the upper point (NRC, 1987). Ruminal motility and passage rate of digesta increase before changes in intake are observed under cold stress conditions, which led Kennedy et al. (1986) to suggest that these responses could be fundamental to the eventual increase in feed intake observed with cold stress.

Predicting Intake

Inherent Variability in Feed Intake and How it Affects Strategies for Prediction

Anyone who has ever fed cattle individually and plotted their daily intakes knows that intake by an individual animal is naturally variable, even with forage-based diets. Forbes (2003) plotted such data for a beef steer fed grass silage ad libitum with a daily allotment of 3 kg of a concentrate feed (**Figure 2**). The pattern of intake was similar to what might be expected with randomly generated data based on the same mean and standard deviation as the observed data. Some evidence generated through examining correlations among days indicated that the variability might reflect a pattern in which intake was responding in a 3- to 4-day cycle, but further experimental work and analyses would be needed to assess that idea. Forbes (2003) used these observations to suggest that this variability in feed intake was related to a control mechanism in which the animal adjusts its intake from day to day in response to discomfort signals. Assuming that this type of pattern, with daily or short-term intake varying considerably over time, very likely occurs in grazing cattle, it is appropriate to question how this variability might affect the measurement of grazed forage intake.

Potential Methods of Predicting Intake by Grazing Ruminants

National Academy of Science, Engineering, and Medicine Equations. The NASEM (2016) provided equations to predict intake by both growing-finishing beef cattle and beef cows. To develop the equation for growing-finishing cattle, published data from experiments conducted from 1980 to 1992 were summarized to yield 185 data points. Values represented average dry matter intake (**DMI**) for periods that varied from 56 to 212 d. Measurements of initial and final BW, information on whether the cattle were fed an ionophore or received a growth-promoting implant (approximately half the cattle), and descriptive information on frame size, gender (steer, heifer, or bull), age (calf or yearling), and initial and final BW were recorded. The NEm concentration of the diets (calculated from tabular values or actually determined in the study) was used to calculate total NEm intake as the product of dietary NEm concentration and DMI, and total NEm intake was scaled to a metabolic BW (**MBW**) basis (using the average $BW^{0.75}$ in kg). The relationship between NEm/MBW and dietary NEm concentration was established by stepwise regression analysis, which accounted for approximately 70% of the variation in NEm/MBW in the literature dataset. The intercept differed between calves vs. yearlings, yielding the following equations:

Calves: NEm intake, Mcal/d = $BW^{0.75} \times (0.2435 \times NEm - 0.0466 \times NE_m^2 - 0.1128)$;
Yearlings: NEm intake, Mcal/d = $BW^{0.75} \times (0.2435 \times NEm - 0.0466 \times NE_m^2 - 0.0869)$;

where BW is the average BW ([initial BW + final BW]/2) for a feeding period, and NEm is the dietary NEm concentration (Mcal/kg of DM). Dry matter intake (kg/d) is calculated from these equations by dividing total NEm intake predicted by the equations by dietary NEm concentration. The NASEM (2016) recommended that the divisor to determine

DMI from these equations be set to 0.95 for diets with NEm concentrations of ≤ 0.95 Mcal/kg of DM.

To predict intake by beef cows, the NASEM (2016) used a similar approach to equation development that was used for growing-finishing beef cattle. Treatment means were compiled from published articles, as well as unpublished theses and data from individual scientists, resulting in 153 observations for DMI (average for a feeding period; 21 to > 200 d) by non-pregnant beef cows or by cows during the middle and last third of pregnancy. Total NE_m intake/MBW was predicted from dietary NEm concentration, resulting in the following equation:

$$\text{NEm intake, Mcal/d} = BW^{0.75} \times (0.04997 \times NEm^2 + 0.04631);$$

the intercept for non-pregnant cows is 0.03840.

As with the growing-finishing beef cattle equation, DMI is calculated by dividing the predicted total NEm intake (Mcal/d) by the dietary NEm concentration (Mcal/kg of DM). Likewise, for low-quality forages with NEm concentrations of less than 1 Mcal/kg (approximately 50% TDN), the divisor should be set at 0.95. Finally, for lactating cows, NASEM (2016) suggested that predicted DMI be increased by a factor of 0.2 × the daily milk production (kg) and also advised users that the equation was probably not applicable for predicting DMI with protein-deficient forages.

Although the growing-finishing and beef cow equations of NASEM (2016) have been used extensively in practice, concerns have been expressed about prediction errors with both equations (Anele et al., 2014; Coleman et al., 2014).

The most unique models presented by Coleman et al. (2014) are the equations for lactating cows. The best measures of a cow’s performance are her ability to rebreed and her calf production, particularly weaning weight. The direct nutritional output from the cow to the calf is milk. Milk production was a positive driver for cow voluntary organic matter intake (**OMI**), accounting for 56% of the variation in adjusted intake. The overall equation that Coleman et al. (2014) presented was:

$$\text{OMI (kg/d)} = 71.6 + 0.015 \times BW - 2.4D + 0.021 \times D^2 - 11.7 \times MP + 0.42 \times MP \times D - 0.0036 \times MP \times D^2;$$

where MP = milk production (kg/d) and D = digestibility (% of organic matter). Lactation causes the gastrointestinal tract to increase in size (Forbes, 1986) and increases voluntary OMI (NASEM, 2016) compared with non-lactating cows, regardless of pregnancy status. Nonetheless, milk production is difficult to measure in production environments. Therefore, including milk production in a general intake prediction equation makes little sense when managers will not likely have these data available.

Two possible surrogates for milk production are calf average daily gain (**ADG**) or calf weaning weight. After examining their data, Coleman et al. (2014) noted that calf ADG is more closely related to milk production. Calf pre-weaning ADG was a good predictor of OMI and explained 64% of the variation when combined with BW and digestibility (**Figure 3**), which is a better predictor than milk production. The following equation describes the overall relationship presented by Coleman et al. (2014):

$$\text{OMI (kg/d)} = 251 - 0.06 \times \text{BW} + 0.00008 \times \text{BW}^2 - 7.6\text{D} + 0.062 \times \text{D}^2 - 265 \times \text{G} + 8.7 \times \text{G} \times \text{D} - 0.07 \times \text{G} \times \text{D}^2;$$

where W = cow BW (kg), D = digestibility (% of organic matter), and G = calf pre-weaning ADG (kg). Thus, calf performance seems to be a good integrator of cow intake by combining cow size and calf growth potential with milk production. Thus, it is logical that calf performance, measured as either weaning weight or ADG, might be more closely related to intake demand than milk production. On the basis of simple statistics (R^2 and residual SE), calf weaning weight was not as good an independent variable as pre-weaning ADG for predicting OMI by cows (Coleman et al., 2014), but the equation is included below because calf weaning weight is probably the easiest metric to estimate:

$$\text{OMI (kg)} = 266 - 0.08 \times \text{W} + 0.00009 \times \text{W}^2 - 8.1 \times \text{D} + 0.067 \times \text{D}^2 - 1.06 \times \text{WW} + 0.036 \times \text{WW} \times \text{D} - 0.00029 \times \text{WW} \times \text{D}^2;$$

where W = cow BW (kg), D = digestibility (% of organic matter), and WW = calf weaning weight (kg). In the very few studies where calf forage intake was recorded, there was little effect on ADG or weaning weight (Ansotegui et al., 1991), but level of milk intake affects voluntary forage intake by the calf (Broesder et al., 1990).

Predicting Intake from Expected or Desired Performance – Dry Matter Intake Required (**DMIR**). Anele et al. (2014) evaluated the feasibility of "back-calculating" DMI of growing-finishing cattle from observed or desired performance data. This approach has been applied in growing-finishing cattle for many years, typically being referred to as "programmed" or "prescription" feeding (Galyean, 1999). This programmed feeding method also has been applied to limit feeding of high-grain diets to gestating beef cows (Loerch, 1996; Gunter et al., 2000). Intake of DM using this approach is calculated by summing the NEm and net energy for gain (**NEg**) requirements of the animal divided by their respective dietary net-energy concentrations.

For this approach to be effective for either growing-finishing cattle or beef cows, assumptions are required, and critical pieces of information are needed. A key assumption is that cattle, at least over an extended period of time, will eat to meet energy needs for maintenance, growth, pregnancy, lactation, and so on. Thus, intake required to meet energy demands would match well with actual intake. As noted previously, intake seems to be highly variable in the short-term, but over the long term, this assumption seems reasonable. Information required includes BW, BCS, ADG, calf birth weights, milk production, and potentially climatic information that could be used to adjust for environmental effects. Perhaps the most critical piece of information is an accurate estimate of the dietary energy concentration. Ultimately, NE values are needed, but these are often determined from total digestible nutrients (**TDN**), digestible energy (**DE**), or metabolizable energy (**ME**) values (NASEM, 2016). For cattle in confinement fed stored and milled concentrates, this information is readily obtainable and probably reasonably accurate. For cattle grazing forages, however, where selectivity of plant parts and plants species comes into play, as well as changes with advancing forage maturity, the reliability of energy values is open to question. This challenge is not unique to the DMIR approach because an energy value (or digestibility value as a proxy for energy) is also needed to predict DMI in the NASEM (2016) and Coleman et al. (2014) equations. Indeed, energy values for grazed forages are generally a “missing piece of the puzzle” when it comes to predicting DMI.

An Example of Applying the DMIR Approach. Developing a database to test the validity of using the DMIR approach in a manner similar to what Anele et al. (2014) did with growing-finishing cattle is technically impossible because grazed forage intake is measured indirectly. Thus, the “observed” intake is not directly measured and is subject to several potential sources of error. Nonetheless, it is possible to use data from confined livestock fed forage-based diets in which DMI, BW, and other production characteristics are measured by direct methods to evaluate how well the DMIR approach predicts observed DMI. Two studies from the literature were selected for this exercise that included growing heifers and beef cows. A brief description of each study follows. It should be noted as these examples were evaluated, however, that measurements of DMI with confined cattle are not made without error, and depending on the method, these errors could be substantial.

Buskirk et al. (1992) used 24 Angus cows to evaluate the relationships between energy intake, BW change, and BCS. Cows were allotted to 4 diets, including high-energy, maintenance-high, maintenance-low, and low-energy concentrations, and penned individually for measurement of feed intake. The DMI, along with changes in BW and BCS were recorded from d 12 to 200 postpartum, and milk production was estimated at 9 different times across the study by the weigh-suckle-weigh method. Trujillo et al. (2013) measured residual feed intake of heifers with potentially favorable allelic variant genes (referred to as the validation group) and a control group without the alleles. Measurements were made in confinement with a 60:40 concentrate:roughage diet and while the cattle were grazing on a high-quality oat pasture. Pasture intake was estimated using an n-alkane technique.

Results for the comparison of the observed DMI with DMI calculated using the DMIR method and the NASEM (2016) equations are shown in **Table 1**. Observed minus predicted values ranged from as little as 3.2 to 42.6% of the observed DMI for the DMIR method compared with 3.4 to 25.5% for the NASEM (2016) prediction equations. The DMIR method generally under-predicted DMI, which also was true for the NASEM (2016) equations. Of both studies evaluated, the predicted DMI values most closely matched the observed values for the Trujillo et al. (2013) study. This particular study was arguably the “simplest” of the studies, as the only energy requirements tabulated were for maintenance and gain. Determining requirements for pregnancy was challenging for studies involving pregnant females because of lack of clarity in terms of the number of days pregnant and the failure to report calf birth weights, which is needed to calculate the NEm requirement. Prediction errors with the DMIR method for lactating beef cows (e.g., Buskirk et al., 1992) were particularly large, perhaps suggesting that refinement is needed in the NASEM (2016) maintenance requirements for lactating cows or that maintenance/lactation energy needs vary more with milk-producing ability of beef breeds than is currently accounted for in requirement equations. Finally, it is interesting that the DMIR method greatly under-predicted DMI with the high- and medium-grain diets in the Buskirk et al. (1992) study, but the predicted DMI was fairly close to the observed value for the low-energy diet.

Overall, the results for the DMIR method are somewhat disappointing. This might not be a particularly surprising result, however, as the net energy equations of NASEM (2016) are population-based equations, generally derived from empirical regression approaches that are not necessarily refined to the extent that they will fit all breed types and production/environmental settings. Biological variation in some of the components of these equations is large, and in many cases, the extent of such variation is not well-defined, particularly when it comes to grazing animals. For a definitive test of the DMIR approach with forage-fed and grazing cattle, a much larger and more robust database is needed.

Conclusions and Recommendations

Predicting intake by beef cattle raised in confinement and fed mixed or all-forage diets of consistent composition is not an easy task. Feed intake by beef cattle varies substantially from day to day. As a result, the “best” empirical equations with feedlot cattle, which are designed to predict DMI over extended periods of time, have prediction errors approximating 5% of the mean, with unexplained variation typically in the range of 25 to 50%. For grazing situations, where added variation results from selective grazing, sward characteristics, effects of advancing forage maturity, pre- and post-ingestive factors, social factors, climatic effects, landscape-related factors, and a host of other ill-defined effects, one would expect even greater prediction errors and more unexplained variation. Empirical equations can provide estimates of intake in grazing cattle, as can the DMIR method, which relies on the idea that energy demand drives long-term feed intake, thereby allowing energy requirements and diet energy concentrations to be used to predict DMI.

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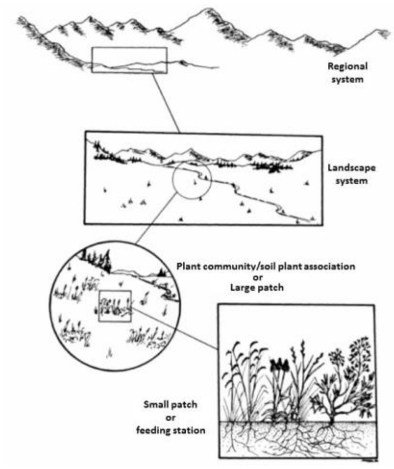

Figure 1. Different extents of spatial and temporal scales experienced by grazing cattle. Adapted from Senft et al. (1987), and published with permission from the Oxford University Press.

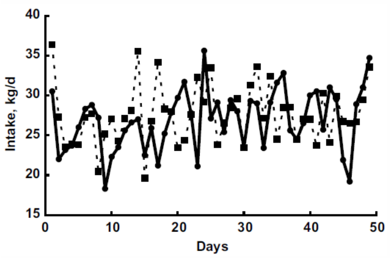

Figure 2. Intakes of grass silage by a beef animal. The solid line represents the observed data, whereas the dashed line represents random numbers with the same mean and standard deviation as the observed data. Adapted from Forbes (2003), and published with permission from the American Society of Animal Science.

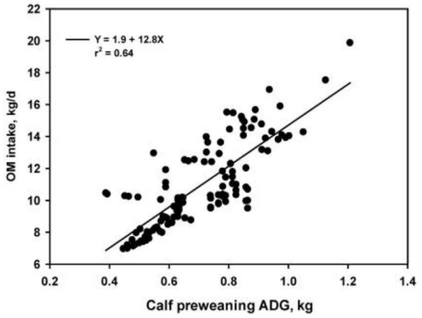

Figure 3. Relationship between OMI by cows and calf pre-weaning ADG. Adapted from Coleman et al. (2014), and published with permission from the American Society of Animal Science.

Table 1. Comparison of observed DMI and DMI predicted from observed performance (DMIR) and NRC (1996) equations

			kg/d				
Study/Group	Avg sBW, kg[1]	Diet NEm, Mcal/kg[2]	Obs DMI	DMIR[3]	Obs-Pred	NRC (1996)[4]	Obs-Pred
Buskirk et al. (1992)							
High	576	2.07	19.0	10.4	8.7	16.1	2.9
Maintenance-high	554	1.54	15.9	11.6	4.2	13.3	2.6
Maintenance-low	495	1.20	12.6	10.9	1.7	11.2	1.5
Low	471	1.12	9.8	10.4	-0.6	10.8	-1.1
Trujillo et al. (2013)							
Confinement-validation	214	1.61	6.7	6.3	0.3	5.5	1.2
Confinement-control	212	1.61	6.9	6.3	0.6	5.5	1.4
Grazing-validation	317	1.75	8.8	8.3	0.5	8.4	0.3
Grazing-control	327	1.75	10.9	8.4	2.5	8.6	2.3

[1]Average shrunk BW (0.96 × live BW was used when shrunk BW was not reported).

[2]Diet NEm concentration, DM basis.

[3]DMIR = DMI required to achieve observed performance based on NRC (1996) equations.

[4]NRC (1996) = equations for growing-finishing beef cattle and beef cows were used to predict DMI.

SESSION NOTES