Application of the California Net Energy System to grazed forage: feed values and requirements

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ABSTRACT: The California Net Energy System (CNES) has been successfully used for many years to generate estimates of grazing animal energy requirements, supplemental needs, and energy value of grazed forage diets. Compared to pen feeding situations, validation of feed nutritive value estimates or animal performance projections are extremely difficult in grazing animals because many of the system inputs are constantly changing. A major difficulty in applying this or any energy accounting system in the field is acquiring accurate estimates of forage intake. We discuss the various equations available to estimate forage intake for grazing animals with emphasis on beef cows. Progress has been made in recent years although there remains substantial discrepancy among various equations, particularly in the upper range of forage digestibility. Validation work and further development is needed in this area. For lactating cows, our conclusion is that the adjustment of intake for milk production (0.2 kg increase in forage intake per kg of milk produced) needs to be increased to a minimum of 0.35. A particular challenge with the CNES for grazing beef cows is the dramatic interaction that can occur between genetic potential for production traits and nutrient availability. Examples from literature are provided and a case study is presented demonstrating that energy requirements are dynamic and depend on nutrients available in grazing systems. The CNES is a useful tool in grazing beef cattle management although there remains substantial opportunity and need to improve inputs and validate the system in grazing situations.

Key words: beef cattle, California Net Energy System, genetic × environment interaction, grazing systems, nutrient partitioning

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INTRODUCTION

Previous and current versions of Nutrient Requirements of Beef Cattle (NRC, 1984; NRC, 1996; NASEM, 2016) use the California Net Energy System (CNES) as a basis to determine energy requirements and feed or forage intake of beef cattle. Even though the CNES was developed using data from pen-fed animals, most computer models apply this system to estimate grazing beef cattle nutrient requirements, supplemental energy needs and as a component in equations to predict forage intake. The application of this empirical system in grazing situations is a challenge because many of the required inputs cannot be measured directly. For example, in confinement feeding, the manager has control over dietary nutrient density, daily ration amount, pen or lot size and therefore physical activity and in limit-feeding situations, the number of feeding events. In addition,

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in most pen-feeding situations, animals have limited ability to adapt to their immediate environment. In contrast, grazing conditions are dynamic with ever-changing forage availability and nutritive value. In more extensive grazing systems, animals have the opportunity to modify their behavior to adapt to current conditions (Caton and Olson, 2016; Galyean and Gunter, 2016) and in many cases, to be selective in diet composition. Relatedly, large data sets generated under relatively uniform management and environmental conditions are not available for model development or validation such as is the case for pen-fed finishing and dairy systems. Consequently, accurately predicting grazed forage nutritive value, forage intake and nutrient requirements can be problematic to say the least.

DISCUSSION

Forage Intake

An estimate of forage intake over a grazing period is a critical element if one is to use the CNES to predict performance, determine appropriate supplementation programs or estimate efficiency of energy use in grazing beef cattle. In fact, 50 years after the introduction of the CNES, we still do not have a reliable method to measure forage intake of grazing animals. For many years, grazed forage intake has been approximated in research settings using markers and forage disappearance methods (Burns et al., 1994). However, in production settings most beef cattle computer models require an estimate of forage intake using a prediction equation. Difficulties associated with estimating forage intake of grazing cattle were recently reviewed (Coleman et al., 2014; Galyean and Gunter, 2016). Several meta-analyses have been conducted for the purpose of developing prediction equations (NRC, 1996; Bandyk and Cochran, 1998; Moore et al., 1999; Coleman et al., 2014). Figure 1 shows the relationship between metabolizable energy (ME) concentration in forage and predicted dry matter intake (DMI) for non-lactating mature beef cows using four different equations. Three equations were published as part of the meta-analyses mentioned earlier (NRC, 1996; Moore et al., 1999; Coleman et al., 2014). The fourth equation was generated from tabular values first published by Hibberd and Thrift (1992) and recently approximated in graphical form by the NASEM (2016) committee. The equation is as follows:

$$\text{DMI, \% of BW} = -1.5583 \times \text{ME}^2 + 7.991 \times \text{ME} - 7.5652$$

where body weight (BW) is the average shrunk BW for a feeding period and ME is feed ME, Mcal/kg (Dr. T.A. Thrift, personal communication, September, 2018). For all equations predicted DMI, expressed as a percent of shrunk BW, is plotted over the range of forage digestibility commonly encountered by grazing cattle (NASEM, 2016; 47% to 72.5% total digestible nutrients requirement (TDN), 1.7 to 2.6 Mcal ME, and 0.86 to 1.71 Kcal NEm). All equations reflect diet DMI when adequate degradable protein is supplied and would therefore include the energy and dry matter supplied by the supplement when a protein deficiency exists. Predicted organic matter intake (OMI) from Coleman et al., (2014) was converted to a dry matter (DM) basis by dividing OMI by 0.92.

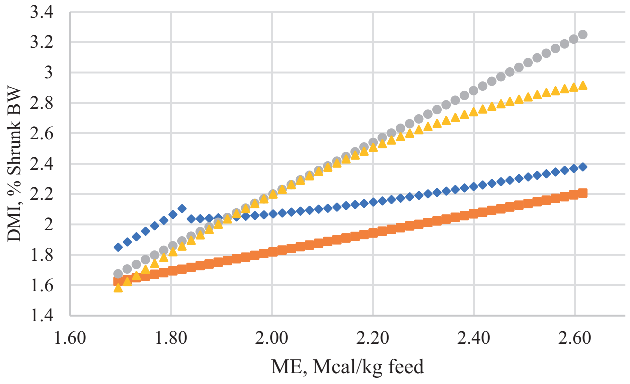

Figure 1. Predicted forage intake for 500 kg dry pregnant beef cows (closed diamonds; NASEM, 2016 equations 19-95 and 19-96; closed squares, adapted from Coleman et al., 2014; closed circles, adapted from Moore et al., 1999; and closed triangles, adapted from Hibberd and Thrift, 1992).

At first glance, it is apparent there is much work left to do in this area. There is little agreement in the different models at the higher end of the range of forage digestibility. However, prediction of low-quality forage intake is consistent at the low end of the range and three of the four models predict similar DMI within the range of 1.8 to 2.0 Mcal ME/kg forage DM. Perhaps a distinguishing characteristic of the Coleman et al., (2014) data is the extensive inclusion of Cr_2O_3 marker-generated intake data for which mean DMI for non-lactating cows was estimated to be 1.5 kg/d lower compared to means generated from direct forage intake measurements. In our opinion, the Moore et al., (1999) equation predicts unrealistically high (and linear) DMI with high-quality forage and this is likely due to inclusion of growing animals along with beef cows in the data set of Moore et al., (1999). All in all, improved systems to determine grazing animal forage intake would be a significant contribution to the CNES or any energy accounting system.

The influence of lactation on feed consumption plays a major role in the successful application of the CNES to cow and calf production systems. Recommended feed DMI adjustment for lactation in NASEM (2016) is 0.2 kg DM/kg increased milk yield. In Brangus cows varying widely in sire milk expected progeny difference (EPD), Johnson et al., (2003) reported this relationship to be 0.33 and 0.37 kg grass hay DMI/kg increased milk yield during early and late lactation, respectively. In the review of Coleman et al., (2014), 0.51 kg increased OMI was associated with 1 kg increase in milk yield ($r^2 = 0.56$). This would be approximately equivalent to 0.55 kg DMI per unit increase in milk yield.

In an extensive review of milk composition reported for beef cows, the NASEM (2016) committee calculated the average net energy per kg of milk contains about 0.72 Mcal NE_m as is. Assuming average forage energy concentration presented in Fig. 1 represents approximate annual average diet energy available in practice, mean annual forage energy concentration would be approximately 1.29 Mcal of NE_m/kg forage (2.18 Mcal ME or 60% TDN). Therefore, the implied increased forage (average quality) requirement is 0.56 kg/kg increased milk yield (0.72/1.29). This calculation assumes no depression in diet digestibility, no increase in maintenance energy requirement because of increased feed intake level and genetic potential for milk production, and no change in the efficiency of ME use for net energy of lactation. Another implicit assumption in this calculation is that all of the additional energy is available for milk production (none is partitioned to maternal tissue gain, mitigation of heat or cold stress or fetal growth). The 0.2 kg/kg milk yield adjustment was originally developed for high-producing dairy cows and may, in part, reflect exacerbated negative energy balance with increasing milk yield (NRC, 2000). Nevertheless, we submit that the impact of increased genetic potential for milk yield on forage intake is substantially greater than 0.2 kg/kg of increased milk production in beef cows.

Estimating Diet Energy Availability

Another challenge for application of energy accounting systems in grazing animals is an accurate estimate of diet DE concentration. Methods to incorporate DE values into net energy systems were reviewed by Dr. Bill Weiss as part of this symposium (Weiss and Tebbe, 2019). In addition, excellent reviews are available discussing methods to determine DE through in vivo digestion trials (Cochran and Galyean, 1994) or laboratory methods (Weiss, 1994). However, diet nutritive value (and specifically DE concentration) changes over time during the grazing period because of the dynamic nature of plant maturity, weather, grazing pressure and therefore leaf:stem ratio, and animal factors such as selectivity, body composition and physiological state (Hodgson et al., 1994).

Nutrient Partitioning and Genetic x Environment Interactions

Beef cows add another level of complexity to successful application of the CNES due to nutrient demands for growth up to about 6 yr of age, conceptus, lactation, and fluctuation in body composition and maintenance requirements associated with increasing and decreasing organ size (Ferrell and Oltjen, 2008). Since the introduction of the CNES in the 1960s, beef cattle have changed dramatically (Kuehn and Thallman, 2016) and these changes were reviewed during the symposium presentation. A positive relationship exists between accelerated genetic potential for growth, lactation potential and mature BW and increased maintenance energy requirements (NASEM, 2016). At this time, the quantitative effects of selection pressure for increased output potential on maintenance energy requirements are not known. This results in a substantial limitation to appropriate application of energy systems, particularly for beef cows that consume diets at or below their maintenance requirements for a good portion of the production cycle.

The animal's forage consumption capacity coupled with the fact that forage maximum energy concentration occurs during the plants' immature growth phase which occurs once annually, combine to set a maximal energy intake potential for the grazing animal (Cline et al., 2010). From this point in the grazing season, energy intake potential (or capacity) declines through the dormant season. As a result, beef cow milk production, body condition gain, calf weaning BW, and growth rate of grazing stocker (yearling) cattle are limited by the grazing environment, unless intervention strategies, such as concentrate supplementation, are used. Therefore, genetic selection for increased output should slow or stop progressing over time when environmental maximum allowable output is reached. There are

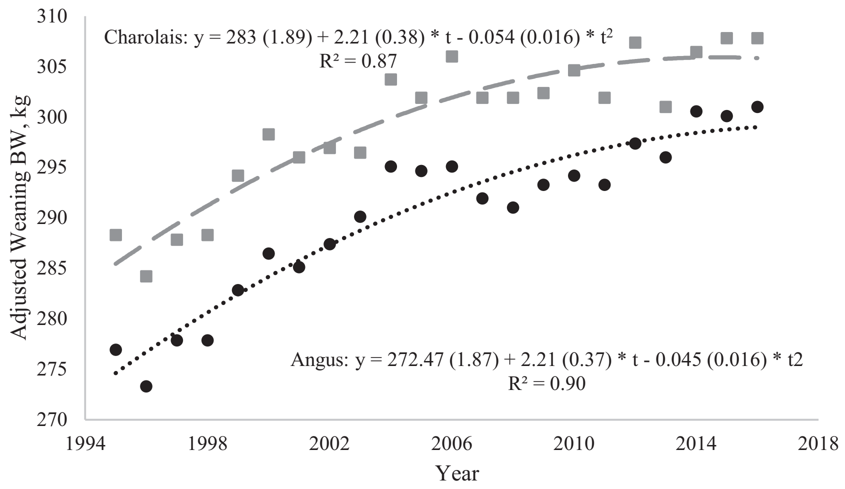

Figure 2. Phenotypic trends for adjusted weaning BW in Charolais (■) and Angus (●) bull calves: 1995 through 2016. Standard errors are shown in parenthesis and all model parameters are significant at $P < 0.01$. Time (t) = Year 1994.

several indications that this phenomenon may be occurring in beef production systems today. For example, in the work of Brown et al., (2005) milk yield in Brangus cows were maximized with slightly above breed average sire milk EPDs. In this study, abundant native tallgrass prairie forage was available to those cows throughout the growing season but daughters of high milk EPD sires actually produced less milk than daughters of moderate EPD sires. Edwards et al., (2017) found that increased milk yield of beef cows resulted in no improvement in calf weaning BW. Their work suggested that selection for greater milk yield in their environment did not improve cow/calf enterprise income, although it may increase expenses and reduce the effective stocking rate. In fact, Lalman et al., (2019) documented weaning BW in commercial cow/calf operations in several large data sets and found that weaning BW has stabilized in some regions of the country. Finally, the phenotypic trend for adjusted weaning BW for Charolais and Angus bulls reveals a slowing rate of increased weaning BW over time (Fig. 2).

Genetic x environment interactions have dramatic impacts on effective application of the CNES, particularly in grazing beef cows. For example, when dietary energy is available in excess of that required for BW stasis in a lactating cow, energy is partitioned to both milk production and maternal tissue gain (Jenkins et al., 2000; Reynolds and Tyrrell, 2000; and Freetly et al., 2006). The partial efficiency of ME use for lactation and maternal tissue energy varies with level of ME intake, stage of lactation, and genetic potential for milk yield (Moe and Tyrrell, 1975; Reynolds and Tyrrell, 2000).

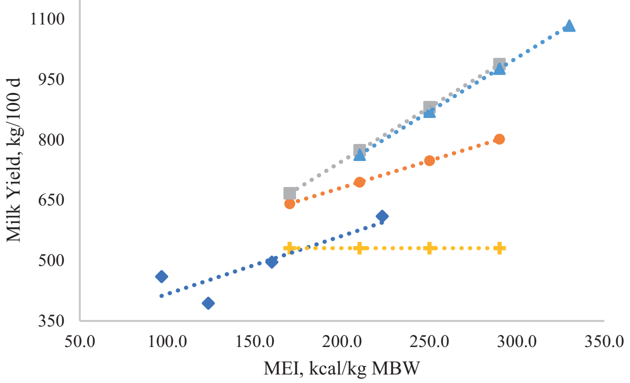

Figure 3. Comparison of milk yield response to increasing ME intake from Buskirk et al., 1992 for Angus cows (♦); Jenkins and Ferrell, 1992 for Angus (●), Gelbvieh (■), Hereford (+), and from Spencer et al., 2017 for Angus (▲).

Figure 3 summarizes treatment means for three different experiments documenting milk yield response to increasing energy intake (Buskirk et al., 1992; Jenkins and Ferrell, 1992; and Spencer et al., 2017). Clearly, the partial efficiency of ME use for lactation differs widely due to breed within a herd, cows within a breed but different herds (Angus) and perhaps years of industry selection for increased milk yield and weaning weight (Spencer et al., 2017).

Computer models could account for relative and variable partial efficiencies if these changes are measurable or at least predictable. In fact, changes in maternal energy stores can be estimated using change in BW and change in body condition score (BCS) (Buskirk et al., 1992; NASEM, 2016), however, in grazing systems, there are no practical ways to determine milk yield, milk energy composition, or maintenance energy requirements.

Table 1. Theoretical feed intake, milk yield, and weight gain for 500 kg beef cows with varying forage quality, milk production potential, and maintenance energy requirement

Diet energy availability	72.5% TDN			62.5% TDN			52.5% TDN		
Milk yield classification	M Milk[1]	H Milk[2]	H Milk	M Milk	H Milk	H Milk	M Milk	H Milk	H Milk
Maintenance classification	M Maint[3]	M Maint	H Maint[4]	M Maint	M Maint	H Maint	M Maint	M Maint	H Maint
DMI, kg/d[5]	13.9	14.7	14.2	12.9	13.3	12.6	11.1	11.1	10.5
Diet ME, Mcal/kg	2.57	2.57	2.57	2.20	2.20	2.21	1.86	1.86	1.87
ME intake, Mcal/d	35.6	37.7	36.5	28.4	29.3	27.9	20.6	20.6	19.6
Maint[3], kcal/kg $BW^{0.75}$	142	142	167	142	142	167	142	142	167
Feed for maintenance, kg	5.7	5.9	6.9	6.8	6.8	8.0	8.1	8.1	9.4
Milk yield, kg/d	10.0	14.0	11.7	10.0	12.2	8.7	4.4	4.4	1.6
Feed for milk, kg	4.2	6.0	5.0	5.2	6.5	4.6	3.0	3.0	1.1
Feed for maternal gain, kg	3.9	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0
Gain	1.06	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00

[1] Moderate milk production potential at peak lactation (10 kg/d).

[2] High milk production potential at peak lactation (14 kg/d).

[3] Moderate maintenance energy requirement (142 kcal ME/kg $BW^{0.75}$).

[4] High maintenance energy requirement (166.5 kcal ME/kg $BW^{0.75}$).

[5] Dry matter intake (kg/d) estimated according to NASEM (2016): kg body weight$^{0.75}$ × $(0.04997 \times NE_m^2 + 0.04631)/NE_m$ + 0.2 × milk yield, (kg/d).

We used the CNES in conjunction with the NASEM (2016) model to generate theoretical energy-limited milk yield potential for beef cows given three different forage quality scenarios (52.5%, 62.5%, and 72.5% TDN), two levels of maintenance requirement (142 and 166.5 Mcal/kg $BW^{0.75}$), and two levels of genetic potential for milk production (10 and 14 kg/d; Table 1). The 52.5% TDN value was chosen to represent forage with approximately 49% to 50% digestibility and a concentrate supplement for the purpose of supplying adequate degradable protein to maximize forage digestion. This range of forage digestibility was intended to span the approximate range of grazed forage digestibility in many parts of the United States throughout the year. Cow BW in BCS 5 was assumed to be 500 kg and maintenance energy requirement was initially set at 142 Mcal/kg $BW^{0.75}$ which represents a 20% increase in maintenance during the lactation phase (NASEM, 2016). The Garrett (1980) equations were used to determine the partial efficiency of ME use for maintenance, lactation, and maternal tissue gain. Equation 10-5 (NASEM, 2016) plus 0.2 × milk yield was used to estimate daily DMI. Milk yield was varied in each model to energy-allowed genetic potential and if additional energy was available, daily weight gain was estimated. In cases where energy availability did not allow maximum milk production, milk yield was adjusted until weight change = zero.

With high-quality forage, moderate milk potential and moderate maintenance requirements, cows were expected to maximize milk yield and gain about 1 kg/d. Assuming increased genetic potential for milk with no change in maintenance energy requirements, cows should be able to produce 14 kg/d of milk although no weight gain would be expected. Finally, in this high nutrient available environment, when maintenance requirement was increased at approximately the same relative amount reported by Montano-Bermudez et al., (1990), cows did not have adequate energy available to produce milk to their genetic capacity.

The 62.5% TDN forage environment resulted in moderate milk, moderate maintenance cows having adequate energy to produce maximum milk and still gain 0.19 kg/d. Cows with greater genetic capacity for milk production did have adequate energy to produce more milk (12.2 kg) although not to their genetic capacity and no energy remained for weight gain. Greater maintenance requirement resulted in projected milk yield being limited to 8.7 kg/d.

Finally, in the low energy environment, milk production was projected to be dramatically limited in all cases. Likely, weight loss would occur in this scenario and maternal tissue energy would be used to support a greater amount of milk production than those projections shown for this scenario in Table 1.

This exercise helps to demonstrate the interactions of grazing system nutrient availability, genetic potential, and maintenance energy requirements. It should be recognized that we intentionally prioritized nutrient partitioning to milk production and secondarily (if excess energy was available) to weight gain. In reality, the biological system is dynamic and the proportion of feed (in the case of excess) or tissue energy (in the case of energy deficiency) partitioned to lactation, maintenance, and weight gain or loss also changes (Moe and Tyrrell, 1975; Reynolds and Tyrrell, 2000).

IMPLICATIONS

The CNES has proven to be a useful tool in management of beef cattle nutrition, particularly for growing cattle in confinement. Applying the CNES in the complex environment grazing cattle are managed in is a challenge. Future research should focus on improving the understanding of environmental effects, genetic potential and physiological state on energy requirements, and availability in grazing animals. However, the CNES provides a useful framework for modeling nutrition in its interaction with genetics, management, and the environment in grazing cattle.

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