Brief Introduction to the NASEM (formerly known as NRC) 8th Revised Edition of the Nutrient Requirements of Dairy Cattle

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Introduction

After 20 years, a new "Dairy NRC" was released in 2021 albeit with new name. The 8th revised edition of the Nutrient Requirements of Dairy Cattle will now be designated as a product of the National Academies of Science, Engineering, and Medicine (NASEM). The Academies have always been the governing unit of the NRC. Although the name has changed, the procedures related to development of the revised edition remained the same. A committee of experts are chosen by the Academy that represents a broad range of expertise and geography, and the committee is vetted for potential conflicts of interest. The final committee was comprised of Rich Erdman (co-chair), Bill Weiss (co-chair), Mike Allen, Lou Armentano, Jim Drackley, Jeff Firkins, Mary Beth Hall, Ermias Kebreab, Paul Kononoff, Helene Lapierre, and Mike Vandehaar.

The main charge of the committee was "to (conduct) a comprehensive analysis of recent research on the feeding and nutrition of dairy cattle, including research on the amounts of amino acids (AA), lipids, fiber, carbohydrates, minerals, vitamins, and water needed by preweaned calves and growing, reproducing, and lactating dairy cattle. . . and to … evaluate new information to improve the accuracy of predicting animal performance from nutrient input and of predicting nutrient input when animal performance is known." The committee was also charged with developing a computer model that reflected the discussion and equations in the text. To meet the last objective, large databases need to be constructed, mostly from published data. Those databases are then used to derive equations to estimate both nutrient supply and requirements. For most vitamins and minerals, inadequate data to generate statistically based equations. In these situations, equations generated from single studies, means from a few studies, and expert interpretation of committee members were used.

It is far beyond the scope of this paper to discuss everything that has been revised (the final book exceeds 500 pages). Rather this brief review will discuss some major revisions from NASEM (2001) and their implications and will be limited to lactating cows even though the chapters on transition cows, calves and heifers have been modified extensively. Some of this will be discussed by other speakers at this conference. Minerals and vitamins were discussed separately at this conference. In addition, areas that need more research to improve equations and incorporate more effects of various nutrients on animal productivity and well-being will be discussed. The amount of text dedicated to different sections does not reflect the importance or magnitude of the changes made, but rather reflects this author's areas of expertise.

Estimating Dry matter Intake

The dry matter intake (DMI) equation in NRC (2001) used only animal factors (milk production, body weight, and days in milk). Because milk yield is strongly related to DMI, the equation was fairly accurate when production measures were known. The equation did not work as well when a diet was formulated without knowing actual production. NASEM (2021) includes an improved animal factor only equation (based on more data and data from higher producing cows) and an animal and diet factor equation. Primary dietary factors that influence DMI are forage NDF (negatively related to DMI), in vitro NDF digestibility (positively related to DMI) and the primary source of fiber in the diet estimated using the ADF/NDF ratio (high ratio indicates a legume-based diet and a lower ratio indicates a grass-based diet). The new equations will be more accurate with today's higher producing cows and reflect the impact of diet on DMI. Users are cautioned that when using the diet factor equation, entered milk yields must be reasonable because milk yield is still the major driver of DMI. Equations to estimate DMI for dry and prefresh cows, calves and heifers were also updated and include dietary NDF (except for the calf equations).

Future improvements. The current feed-animal factor equation is too dependent on milk yield. An accurate equation based mostly or solely on diet factors would allow nutritionists to better determine the production potential of various diets before actually feeding them. The equation estimating DMI during the dry period is much better than the equation in NRC(2001) but it only accounts for one source of dietary variation (NDF concentration). Digestibility of NDF, starch, and source of NDF likely affect DMI prepartum but more data are needed to generate equations to account for that variation. Data with Jersey cows are needed.

Energy

The NRC (2001) was the first revision of the Dairy Requirements series that calculated energy values (i.e., net energy for lactation, NEL) from the nutrient composition of the feeds. Prior to that revision, NEL values of feeds were fixed. In the 2001 system, digestible energy (DE) was calculated for feeds by estimating the energy provided by digestible portions of NDF, CP, fatty acids (FA), and nonfiber carbohydrate (100 – NDF – CP – FA – ash). The DE of the diet was calculated as a weighted mean from feed values, and the diet DE was then discounted based on DM intake (DMI) and TDN concentration of the diet. TDN concentration was essentially a proxy for diet starch concentration. One issue that was identified regarding NRC (2001) was that energy balance (NEL supply minus NEL requirements for maintenance, milk, growth, and reproduction) was underestimated for high producing cows. Because it was a problem with high producing, high DMI cows, the source of the error was assumed to be an overestimation of lactation NEL requirements and/or an underestimation of NEL concentration of the diet likely caused by the discount factor.

Research published after NRC (2001) indicated that the greatest source of error was indeed the discount factor. Dry matter digestibility did not decrease as much with increasing

DMI and diet TDN as the NRC 2001 equation calculated. In NASEM (2021), the digestibility of NDF and starch are reduced as DMI increases but much less than the discount in NRC (2001) (Figure 1). One reason for the error is that NRC (2001) used a cow fed at maintenance (approximately 7 kg of DM) as the base and discounted from there. This resulted in substantial extrapolation and assumed linearity starting at a very low and restricted DMI. The data used by NASEM (2021) was with mostly lactating cows (DMI ranging from about 1.7 to 4.6% of BW with a mean of 3.5% of BW). Because increased dietary starch can depress NDF digestibility, its effect was also included (the base was set at 26% starch which was mean concentration in the dataset used). This approach is much more theoretically accurate than using TDN as done previously. The improved discount equation should correct most of the underestimation of NEL balance in high intake cows by NRC (2001).

Other changes made to the energy prediction equation would be considered fine-tuning. The NFC fraction was replaced with starch and residual organic matter (ROM; i.e., NFC – starch) as outlined by Weiss and Tebbe (2018) and Tebbe et al. (2017). This allows better estimation of the energy provided by a variety of starch sources (e.g., different grind sizes of corn grain, high moisture vs dry corn, different maturities of corn silage). The true digestibility of ROM was set at 96% (Tebbe et al., 2018) and starch digestibility values are constants based on the feed (Table 1). Users can choose to use a lignin-based equation as in NRC (2001) or 48 h in vitro NDF digestibility. An equation is used to convert in vitro digestibility into estimated in vivo digestibility.

Another change was to the true digestibility coefficient used for FA. In NRC (2001) the true digestibility of FA was assumed to be 100% at maintenance DMI (92% for a typical lactating cow). This was based on very limited data because at that time, FA was not commonly measured. Over the past 2 decades a substantial database of FA digestibility was developed and allowed better estimation of the true digestibility of FA. Two meta-analyses have been conducted (Weiss and Tebbe, 2018, Daley et al., 2020) and both derived essentially the same true digestibility value (73%) with no metabolic fecal FA (i.e., intercept was not different from 0). In the NASEM (2021), digestible FA are calculated as 0.73* FA (% of DM). This is substantially lower than the 0.92*FA (% of DM) used in NRC (2001) but the difference is not as great as it appears because in NRC (2001), FA contributed to metabolic fecal energy but not in NASEM (2021). However, the DE concentration of feeds with appreciable concentrations of FA will be lower in NASEM (2021) than in NRC (2001).

In NRC (2001), metabolizable energy (ME) was calculated directly from DE using an equation that was developed several decades ago. That equation did not correctly account for the effect of protein or fat on ME. NASEM (2021) estimates methane using a published equation based on DMI and dietary concentrations of FA (negative effect on methane) and digestible NDF (positive effect on methane). Urinary energy is estimated by estimating urinary N excretion (g/d) and multiplying that value by 0.0143 Mcal/g (Morris et al., 2021). Both methane and urinary energy are calculated for a diet, not a feed. Therefore, feeds will not have ME or NEL values. The change in the method to calculate ME will result in higher ME values for diets with high FA concentrations and lower ME values for higher fiber diets and diets with excess CP. In the previous NRC, NEL was approximately .64*ME. Based on a re-analysis of Beltsville calorimetry data, Moraes et al. (2018) determined that 0.66 was more accurate and that value is used to convert diet ME into NEL concentrations of diets.

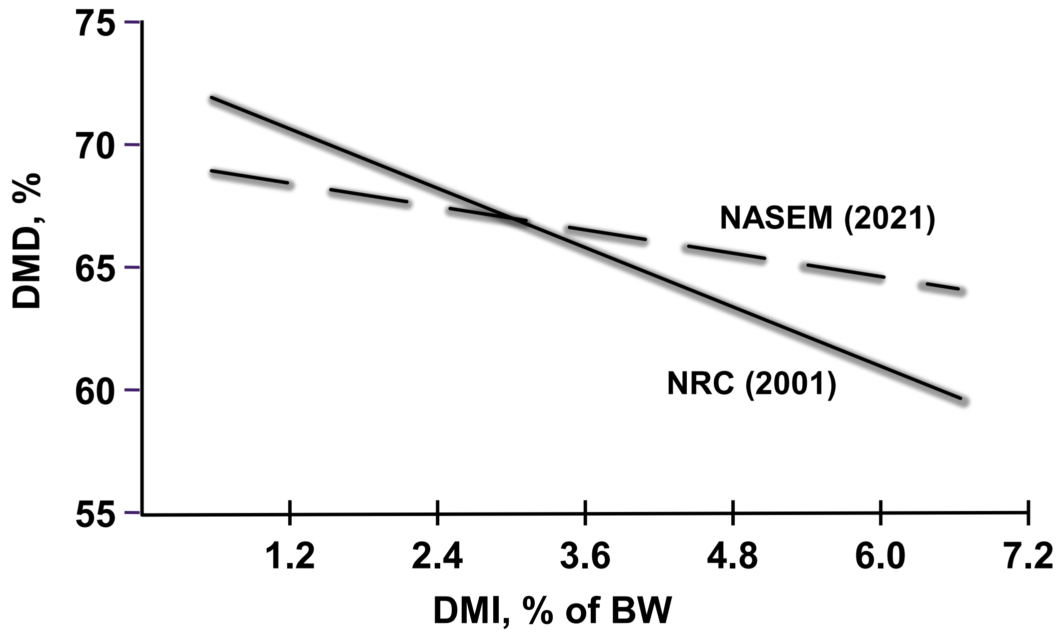

Figure 1. The effect of increasing dry matter intake (DMI) expressed as % of body weight (BW) on dry matter digestibility (DMD) using the NRC (2001) discount equation and the discount equation in NASEM (2021) model. For NRC (2001) diet TDN was set at 72% and for the NASEM line, dietary starch was set at 26%. Overall, the effect of DMI on digestibility (i.e., digestible energy) is about 3 times greater using NRC (2001) than in the updated NASEM.

Energy requirements were also evaluated and modified as necessary. The greatest change was in the maintenance requirement. Several papers published over the past 15 years determined that the standard equation for maintenance (which has been used for more than 30 years) underestimated the maintenance requirement of modern dairy cows. Using an average from several newer studies, the maintenance requirement was increased from 0.08*MBW to 0.10*MBW (where MBW is metabolic body weight in kilograms). This change is a 25% increase in maintenance or about 2.5 Mcal of NEL/day for a 650 kg cow). The equation to calculate gestation energy requirements changed to better model fetal growth but the change did not appreciably alter gestation NEL requirements. Lactation energy requirements changed slightly because the efficiency coefficient (0.66) changed from 0.64. Equations to estimate NEL requirements for grazing cows were updated based on newer data and generally activity requirements will be less when calculated using NASEM (2021) than when using NRC (2001).

Table 1. Starch digestibility coefficients used in NASEM (2021) for selected feeds (not all feeds are shown).

Feed	Starch digestibility
Default	0.91
Corn grain, dry, fine grind (<1250 μm)[2]	0.92
Corn grain, dry, medium grind (1500 um to 3250 μm)	0.89
Corn grain, dry, coarse grind (>3500 μm)	0.77
Corn grain, high-moisture, fine grind (<2000 μm)	0.96
Corn grain, high-moisture, coarse grind (>2500 μm)	0.90
Corn grain, steam flaked	0.94
Sorghum grain, dry, ground	0.83
Sorghum grain, steam flaked	0.94
Corn silage <30% DM	0.91
Corn silage 32 – 37% DM	0.89
Corn silage >40% DM	0.85
Barley, ground	0.91
Wheat	0.93

Future improvements. If laboratory measures can be developed to estimate total tract starch digestibility, they should be incorporated into the energy supply equation. The energy coefficient for NDF is too high based on very recent data from Nebraska. Perhaps incorporating fatty acid composition data will increase the accuracy of estimating fatty acid digestibility resulting in more accurate estimates of DE. On the requirement side, going back to an ME system will be simpler and probably just as accurate as the NEL system unless we can develop specific NEL/ME efficiencies for nutrients. Including body condition in the maintenance equation should improve accuracy (a fat cow will have a lower maintenance requirement than a thin cow at the same BW). More data with Jersey cows are needed.

Carbohydrates

NASEM (2021) has a chapter on Carbohydrates but did not establish requirements or ‘adequate intakes’ for the different carbohydrate fractions. The major fractions discussed are total NDF, forage NDF, starch, and various measures of ‘effective’ NDF. A major change from NRC (2001) was the replacement of nonfiber carbohydrate (NFC) with starch. Recommendations provided by NASEM (2021) follow the same basic relationships as did NRC (2001) but now as concentrations of forage NDF decrease, recommended concentrations of starch decrease (previously concentrations of NFC decreased). The text includes increased discussion of both dietary and management factors that can affect the optimal concentrations of forage NDF, total NDF, and starch in diets. In addition, recommendations for effective NDF as measured by the method of Zebeli (2012) are provided. Zebeli et al. (2012) defines effective NDF as the NDF in the top 2 screens of the Penn State Particle Size box (PSPS) expressed as a percent of diet DM. NASEM (2021) discusses a new concept called physically adjusted NDF. This approach uses several nutrient fractions along with particle size and some cow factors to estimate the optimal amount of diet DM that should be on the 8 mm screen of the PSPS. Because of the uncertainty around the values, this was not included in the software but is discussed in detail in the text.

Future improvements. This is an area that needs substantial research if we are going to change from ‘recommendations’ to more quantitative optimal concentrations or intakes. Appropriate analytical measurements and identification of meaningful response measures are major limitation to progress. The committee identified several issues including the need to measure both DM and NDF concentrations in various particle size fractions. Usually, particle size fractions are assumed to have the same concentrations as the total diet which is clearly wrong. Rumen pH is often used as the response measure but that has questionable value. Do we use mean pH, hours below a certain pH, lowest pH, etc? The fermentability of starch should affect the optimal concentration of effective NDF needed but data do not exist to quantify that relationship.

Protein and Amino Acids

This section underwent the greatest change as compared to NRC (2001) and the complexity of the model precludes a detailed discussion in this paper. Microbial protein is estimated based on estimated rumen digested starch and fiber (these are estimated based on diet composition, not digestion rates). Rumen undegradable protein is based on the A, B, C fraction scheme described in NRC (2001); however rather than estimating rate of passage based mostly on intake as done in NRC (2001), constant rates of passage are used (one for concentrates and one for forages). Significant improvements were made in the estimates for the digestibility of the rumen undegraded protein because the data base was much larger allowing greater screening for spurious values. Supplies of metabolizable protein (MP) and metabolizable AA are the sum of digestible microbial AA or true protein and digestible rumen undegraded AA or true protein. In NRC (2001) endogenous protein was included in MP supply; however, this was an error because endogenous protein does not cause a net increase in MP supply. Therefore, endogenous protein is considered a requirement rather than a supply function in NASEM (2021).

For lactating cows, maintenance requirements are based on both net protein (NP) and amino acids. The requirement for metabolic fecal protein was changed markedly and is now a function of dietary fiber. The calculation for endogenous urinary CP was also changed. In addition, rather than using a classic requirement model for milk protein (e.g., to produce 1200 g of milk protein you need X grams of MP or specific AA) a response model is used (based on AA and energy supplies, the cow should be able to produce X grams of milk protein). The response function for milk protein yield is based on DE supply (the DE is from components other than CP) and supply of lysine, methionine, leucine, isoleucine, histidine, and total essential AA. The equation to estimate milk protein yield illustrates that an almost infinite array of AA profiles can result in similar milk protein yields. The efficiency of converting MP to NP for maintenance function is 0.68. Efficiency of converting metabolizable AA to milk protein is not fixed as it was for MP in NRC (2001). The function includes a quadratic term for total essential AA which means efficiency decreases as supply of essential AA increases. The software calculates 'target efficiencies' which help users determine which AA are mostly likely limiting and it also calculates expected response in milk protein yield if supply of certain AA change.

Future improvements. The equation used to calculate microbial protein does not include important sources of variation (e.g., high moisture corn will produce the same microbial protein as dry corn) and needs to be expanded. The AA composition of digestible RUP is assumed to be the same as the feed which may or may not be true. More data on AA requirements for maintenance functions are needed. The equation used to estimate milk protein yield is empirical and based on data generated several years ago. More data are needed to validate its accuracy with high producing cows.

Minerals and Vitamins

These nutrients are discussed in another paper in these proceedings; therefore, this section will concentrate on future improvements.

Future improvements. Much less research is published on minerals and vitamins than for macronutrients such as AA, protein, and energy and therefore we have more uncertainty associated with mineral and vitamin requirements or adequate intakes. A major limitation to the current system is the lack of absorption data for most minerals. For most minerals we have almost no data on their true absorption by cows, and the data we do have is often more than 60 years old. Measuring true absorption is very difficult and expensive (it usually requires the use of stable isotopes) which is why data is so limited. In addition, we know antagonistic relationships exist among many minerals but in general we do not have adequate data to quantify the effects. For example, increased dietary sulfur reduces copper absorption but we do not know exactly how much. We have virtually no information on absorption of vitamins or factors that affect absorption. For many minerals and vitamins, we do not have sensitive status indicators so we cannot develop recommendations based on optimal status. Currently we often rely on clinical health data (e.g., reduction in incidence of mastitis) but these studies are expensive and require lots of cows. This limits most experiments to just 2 treatments which is inadequate to fine tune recommendations. Lastly the factorial method used to establish requirements for minerals does not include everything minerals do. For example, several trace nutrients are needed to elicit strong immune responses, but the factorial method does not include a requirement for health.

Conclusions

The 8th revised edition of the NASEM (formerly NRC) Nutrient Requirements of Dairy Cattle reflects the current state of knowledge for applied dairy nutrition. All facets of nutrition for calves, heifers, dry cows, and lactating cows were reviewed and changes in requirements were made when appropriate. The book also contains up to dates reviews on numerous topics relevant to feeding dairy cattle. The new revision is an improvement over NRC (2001), but the new revision also identified areas where improvements are still needed, and the book should be used to focus research on those areas.

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