Teaching with the narrative and model in NASEM (2021) ‘Nutrient Requirements of Dairy Cattle’

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Chapter 1

About this module

1.1 Purpose

The consensus report "Nutrient Requirements of Dairy Cattle, 8th edition" (NASEM, 2021) summarized decades of dairy nutrition research into narrative text and a mathematical model available for public use. This module and its accompanying resources for teachers are intended to promote learning from the NASEM (2021) consensus report. Because the NASEM (2021) narrative and software were designed for advanced dairy nutrition practitioners, they may be difficult for less-experienced learners. Our module is designed to highlight core concepts that will assist learners in understanding the NASEM narrative and utilizing the mathematical model in practice.

Learning Objectives of this Module

1. Raise learners' knowledge and confidence working with nutritional models, using the example of the NASEM (2021) "Nutrient Requirements of Dairy Cattle"

1.2 Structure of the module and materials for teachers

1.3 Assumptions about prior knowledge

This module can be used by anyone, but it has been designed with the assumption that learners have some prior knowledge. Before starting this module, we suggest that learners should have:

- Intermediate understanding of nutritional physiology of ruminants, e.g., have taken an animal nutrition course

Figure 1.1: Cover of 'Nutrient Requirements of Dairy Cattle, 8th edition'

- Intermediate knowledge of dairy production systems, e.g., through an introductory animal science or management-focused course, or through personal/career-related experiences
- Basic skills with statistics and math (mean, standard deviation, regression)

1.4 Technology requirements

- To read the narrative and complete activities, need a computer and stable internet connection
- To run NASEM-8 software, need Windows operating system

1.5 Accessing the NASEM (2021) Consensus Report

The NASEM (2021) "Nutrient Requirements of Dairy Cattle" consensus report is a distillation of our collective knowledge about dairy cattle nutrition in the U.S. in the form of written text and mathematical equations. The most recent edition (8th), hereafter referred to as NASEM (2021), includes two parts. First, a 502 page consensus report book describes advancements in the dairy nutrition literature in recent decades in the form of narrative text and prediction equations. Second, a software for Windows enables users to evaluate diet adequacy for a given scenario using the prediction equations given in the book.

1.5.1 The narrative

The NASEM (2021) book provides a narrative that summarizes recent scientific literature on dairy nutrition and justifies choices made while developing the mathematical model. The narrative is rich with information on nutritional physiology, dairy herd management, dairy nutrition experimentation, and the model development process. Due to its information density and use of technical language, it may be overwhelming to read for less-experienced practitioners. For this reason, learners may find it helpful to read the NASEM (2021) book in a class or small-group setting where it is possible to ask questions and verify their understanding.

Instructors and learners can work together to determine which sections of the text are appropriate to the learners' current comprehension level. For intermediate learners, it may be best to complete this module first before spending much time reading the NASEM (2021) narrative. Advanced learners may be able to read through the NASEM (2021) Consensus Report simultaneous to completing the activities in this module. In some cases, learners may benefit from approaching the narrative in an informal "Journal Club"-style setting (arranged either by teachers or students!).

Accessing NASEM (2021) consensus report

At the time of writing, a print version of the NASEM 8th edition book is available for purchase at the link below. Eventually this material will be available to read for free online. https://nap.nationalacademies.org/catalog/25806/nutrient-requirements-of-dairy-cattle-eighth-revised-edition

Earlier editions, e.g., 7th, NRC (2001)

Earlier editions of "Nutrient Requirements for Dairy Cattle" are available to read for free online, for example, the 7th edition (2001): https://nap.nationalacademies.org/catalog/9825/nutrient-requirements-of-dairy-cattle-seventh-revised-edition-2001

1.6 The NASEM-dairy-8 software

Most of this module can be completed without using the NASEM-dairy-8 software. However, learners are encouraged to download and experiment with the NASEM dairy-8 software on their own time. Download instructions are available on the NASEM website: https://nap.nationalacademies.org/resource/25806/Installation_Instructions_NASEM_Dairy8.pdf

The NASEM dairy-8 software runs only on Windows operating system. Learners who wish to run NASEM dairy-8 can install it on a personal computer or a campus library computer. Learners with non-Windows operating system may be able to download the NASEM dairy-8 using virtual machines through platforms such as Virtual Box (https://www.virtualbox.org). However, this requires substantial computer expertise and may be inconvenient for everyday use.

The easiest way to get started running NASEM-8 is to Load a pre-defined simulation.The software comes with several pre-defined simulations for different classes of animals (e.g., "Example Lactating Cow 100 DIM"). Loading a pre-defined simulation pre-loads all of the inputs describing an example animal, management scenario, and diet. This can be helpful to avoid entering unrealistic inputs.

To run NASEM-8, users proceed through four sections:

1. **Inputs.** In the first panel, users must specify the Program Settings. Most commonly, the default settings (Metric, Dry Matter) can be retained. In the second panel of Inputs, "Animal Description/Management" users can provide detail about the animal (e.g., age, breed, days in milk) and the management scenario (e.g., grazing vs. no grazing). Finally, the "Production" panel allows users to specify the expected rates of growth, changes in body reserves, and milk and component production.
2. **Feeds**. In this section, users can select the feedstuffs that will comprise the ration ("Add Feeds to Ration"). The software is pre-loaded with a default Feed Library, which contains composition information for over 300 feeds

commonly used in dairy rations. Ingredients in the feed library can be modified to create custom feeds ("Edit feed components and nutrients"), which users can save to the feed library (Save Feed in Feed Library) for later use. This section defines which feeds are used in the ration, but not the inclusion rates.

3. **Ration**. Feeds selected in the prior section will appear in the Ration List. To create a ration, users enter either the amount of dry matter (DM) consumed or the feed's percent of total diet DM. The bottom of the screen allows users to specify DMI manually ("Total Intake") or to select from two estimated intakes produced by the NASEM model using the animal characteristics (e.g., milk production, parity, body weight). Using the "Set to 100%" allows users to easily scale diet information to 100%. This can be helpful to correct rounding errors (e.g., to fix ingredient composition that sums to 100.01 or 99.99% of DM). A sidebar shows quick estimates of the diet nutritional value, which makes it easier to tweak the ingredient composition to meet goals.

4. **Reports**. Finally, users can generate reports detailing the predictions from the NASEM (2021) model. Nine types of reports are available. By selecting "10. All" and "Generate Selected Reports," a Word document is created and opened. Users can look through the Word document to see predicted nutrient supplies and requirements associated with their inputs. It is also possible to generate an excel spreadsheet with the nutrient composition of ingredients. This may be helpful for users who wish to do their own manual calculations.

Some of the most common mistakes when using NASEM dairy-8 relate to improper inputs. For example, a user could enter a body weight of 7,000 instead of 700 kg in the Animal Description; or create a custom feed with unrealistic nutrient composition. For this reason, it is easiest to use pre-loaded simulations and default Feed Library ingredients in classroom settings. This will prevent many hours of troubleshooting related to improper inputs.

Accessing NASEM-dairy-8 software

The NASEM-dairy-8 software for Windows is available to download as shown here: https://nap.nationalacademies.org/resource/25806/Installation_Instructions_NASEM_Dairy8.pdf

Earlier software, e.g., NASEM-dairy-7

It is also possible to download the Windows software for NRC (2001), although NASEM recommendeds against having both NRC 2001 and NASEM 2021 software installed on the same computer. https://nap.nationalacademies.org/catalog/9825/nutrient-requirements-of-dairy-cattle-seventh-revised-edition-2001

1.7 Suggested citation

If you use this module, please give credit by citing our work and the NASEM report.

Cite our abstract on this module:

Erickson, M.G., Hanigan, M.D., and Wattiaux, M.A. (2023). Teaching with the narrative and model in NASEM (2021) "Nutrient Requirements of Dairy Cattle." Proceedings of the American Dairy Science Association Annual Meeting in Ottawa, Ontario, Canada.

Cite the consensus report:

National Academies of Sciences, Engineering, and Medicine. (2021). Nutrient Requirements of Dairy Cattle: Eighth Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/25806.

1.8 Contribute to this module!

Interested in editing or adding to this instructional module? Please share your ideas with our team (merickson3@wisc.edu) so we can incorporate them and acknowledge you as a contributor.

1.9 License details

Chapter 2

Introduction to nutritional models

Learning Objectives

1. Explain the rationale and history behind nutrient models.
2. Describe how nutritional models are developed, step-by-step.
3. List and differentiate common dairy nutritional models.

2.1 A brief history

Figure 2.1: Cattle painted circa 7000 years ago in the Libyan Sahara (Sapienza University of Rome)

Deliberate animal feeding began before recorded history with the advent of agriculture in Asia and Africa 12,000 years ago (**?**). Since this time, humans have carefully considered how to manage forages, grains, minerals, and other natural resources to provide nourishment for domesticated animals. In regions throughout the world, traditional and indigenous knowledge systems contain a wealth of information on animal nutritional management, yet very little of it is recorded in publications and books.

Primarily in the last 200 years, animal nutrition developed as a scientific discipline. The use of scientific methods enabled researchers to isolate the chemical components of feeds and to quantitatively relate dietary intakes to physiological effects. As nutrition science progressed, nutritional diseases that had once harmed or killed thousands of animals (and people) began to be curable. The productivity of agricultural animals began to increase. As per the scientific method, advances were recorded with detailed publications in the scientific literature to enable cumulative progress.

In the United States, nutrition science was spurred by government efforts to reconstruct and reduce poverty after wars. In the aftermath of the Civil War and World Wars, the U.S. government chartered the National Academies of Sciences, Engineering, and Medicine (NASEM) and its subsidiary organization the National Research Council (NRC, **?**). NASEM is a non-governmental, non-profit organization of academics whose mission is to translate scientific information into domestic policy and practice. In animal nutrition, NASEM is famous for organizing efforts to consolidate nutritional science knowledge into animal feeding recommendations by publishing consensus reports.

The first edition of "Nutrient Requirements of Dairy Cattle" was published by the NRC (NASEM's subsidiary) in 1945. In the eight decades following, researchers created seven more editions of this consensus report. Each edition uses the most up-to-date research on dairy cattle nutrition generated by researchers at universities and government institutions.

2.2 Definition

Test Yourself: Before proceeding, we need to ask ourselves…what are nutritional models, and what do they have in common with the cave paintings shown at the beginning of the chapter?

The cave painting of cattle is a two-dimensional representation of three-dimensional animals. It conveys some information about cattle and how they are shaped. Although we cannot know the intention of its artist(s), perhaps they meant to use the cave painting to communicate some information about cattle they had observed. The painting is a "snapshot" in time that summarizes and communicates about cattle.

A nutritional model (for example, the NASEM dairy model) is also a representation of cattle. Instead of a two-dimensional artwork, nutritional models are generally represented mathematically. The tens or hundreds of mathematical expressions that comprise a nutritional model are intended to summarize and communicate what we know about cattle nutrition. Similar to the painting, a model is a representation of reality.

2.3 Usefulness

Models are mathematical and/or statistical descriptions of inputs, processes, and outputs. Nutritional models function as decision-support tools that can use known information (e.g., feed composition, animal characteristics) to predict how nutritional processes will unfold and what outcomes will result. They can be used to answer various types of questions.

Scenario 1

> A dairy nutritionist has access to many different feedstuffs with known chemical composition. They have several different pens of animals to feed (e.g., calves, dry cows, lactating cows, high-producing lactating cows). How do they create diets for each pen of animals?

A nutritional model can help determine the requirements for each pen of animals. Additionally, the nutritional model can determine which feeds can be combined to create diets that meet the requirements.

Scenario 2

> A group of dairy producers aims to reduce greenhouse gas emissions from their farm so they can reach carbon-neutral production goals. How can they select diets that contribute to their environmental goals?

A nutritional model could help these producers predict the environmental impact of their current production practices, or explore hypothetical alternative diets and scenarios.

Scenario 3

> A dairy nutritionist has a suspicion that a group of cows is not producing as much milk fat as they could be, given the diet and animal characteristics. How does the nutritionist test their hypothesis?

A nutritional model can be used to benchmark production. Benchmarking means comparing the observed value against a reference value to evaluate its adequacy. In this case, the nutritionist could enter the diet and cow information to predict the expected milk fat production under these conditions. Then, they could compare this reference (expected) value to their observed value to benchmark.

Scenario 4

> Feed costs for certain ingredients have changed, and a nutritionist wants to ensure they can meet animal needs and maintain performance at the least possible cost. How can they create a diet that minimizes feed costs?

A nutritional model can be used to optimize diets based on certain constraints. For example, least cost formulation is a common approach. It involves finding the combination of ingredients that will create a diet that meets animal requirements and costs the least amount.

2.4 Development

Nutritional models are developed through the scientific process. To get a sense of how nutritional models work, let's go through a fictional example to develop our own (very simple!) nutritional model.

- Hypothesis generation
- Data collection (through observation and experimentation)
- Model development
- Model verification and generation of new hypotheses
- ...repeat the process ad infinitum

2.4.1 Hypothesis generation

Imagine that a researcher is observing some cattle, and notices that larger cattle seem to eat more. They write this observation into their notebook.

2.4.2 Data collection through observation (or experimentation)

To learn more about the hypothesized relationship between body size and feed intake, the researcher decides to find a group of cattle to collect observational data. They collect two pieces of information in each observation: 1) the animal's body weight (BW), and 2) the animal's dry matter intake (DMI). They use the data to create a plot:

Test Yourself: What would you conclude from the plot?

After looking at the plot, the researcher believes that DMI and BW are related. In other words, if an animal's BW is known, its DMI can be guessed with some accuracy. The researcher decides to convert this observed relationship to a mathematical model. Because the relationship seems to follow a line, they fit a regression with the linear form $y = mx + b$.

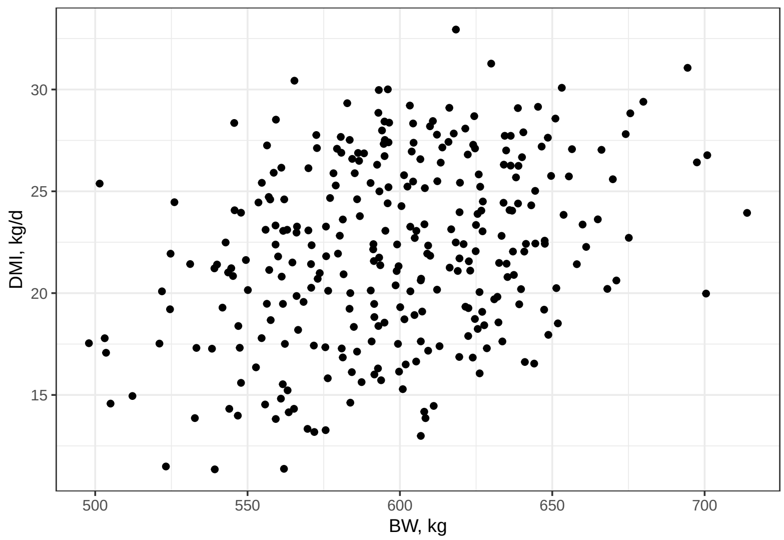

Figure 2.2: DMI vs BW for 300 observations from lactating cows

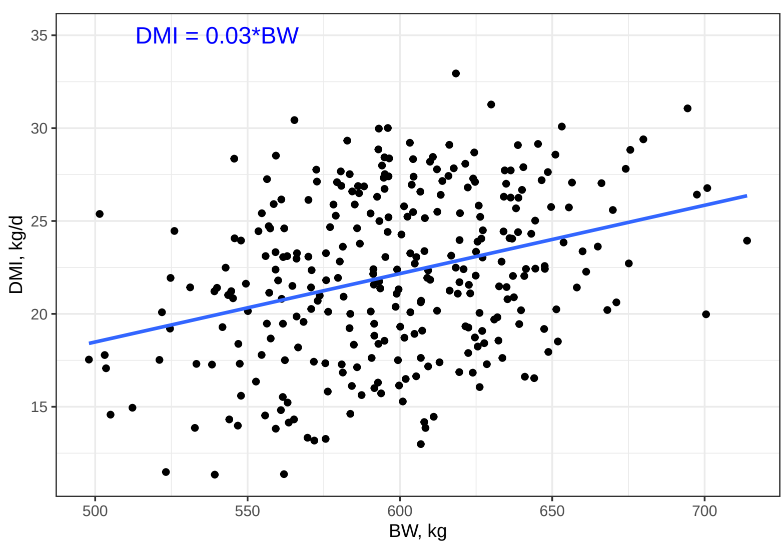

Figure 2.3: Fitted regression model predicting DMI from BW for lactating cows

2.4.3 Model development

By fitting a regression model to the observed points, they get an estimate of the slope (0.03) that relates BW and DMI. In other words, the average DMI observed was 3% of the animal BW. This single mathematical expression is a very simple nutritional model: $DMI = 0.03 * BW$

The researcher thinks the model will be useful for prediction. They decide to test the predictive performance of the model by buying a new lactating cow. They record the cow's BW as 625 kg.

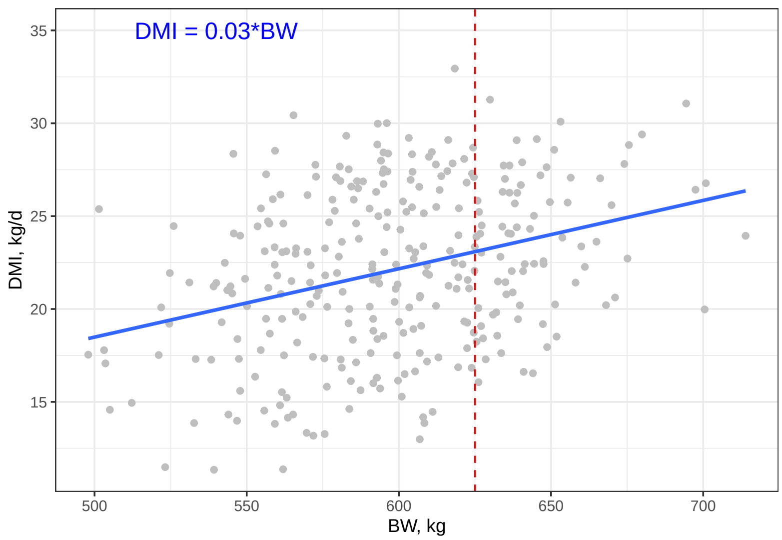

Figure 2.4: Fitted regression model predicting DMI from BW for lactating cows

Test Yourself: Using our simple nutritional model, what is this cow's predicted DMI?

2.4.4 Model verification

To predict the DMI of the new cow, the researcher enters the known information (cow's BW) into the nutritional model: $DMI = 0.03 * 625$. The model predicts the cow's DMI will be 18.75 kg. Tracing up from the x-axis, the intersection of the red dashed line with the blue line shows the predicted DMI for an animal with BW = 625.

Next, the researcher decides to verify their model by measuring the animal's actual DMI.

Uh oh.... the actual DMI observed is shown with the large red point. It is greater than the prediction. This means that the model under-predicted the actual DMI for this cow based on her BW. This causes the researcher to go

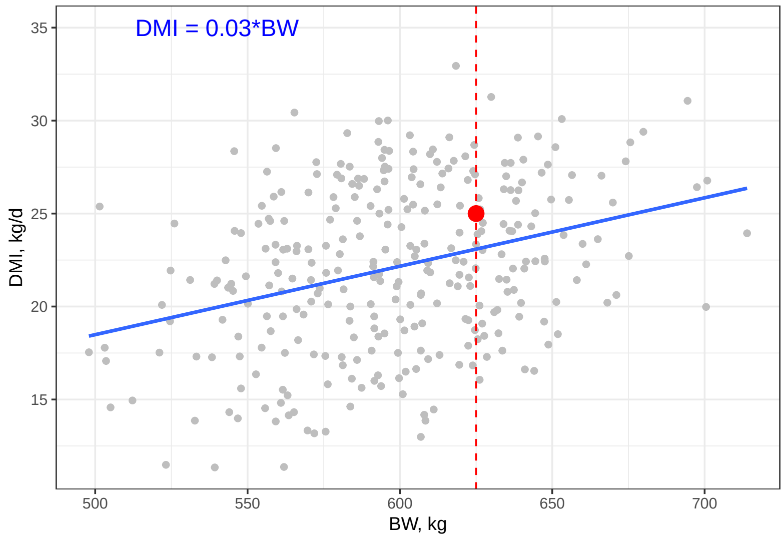

Figure 2.5: Actual DMI for a new observation (red point) of a cow with BW = 625 kg

back to their original model, $DMI = 0.03 * BW$. The variable BW seems to explain some, but not all of the variation in DMI.

Test Yourself: What should the researcher do next?

There are several courses of action to be considered. First, the researcher could leave the model as-is, and attribute the error in prediction to un-explainable variation. Un-explainable variation comes from unknown and un-measurable sources, including the intrinsic randomness of the universe. Second, the researcher could try to gather more information to find other measurable predictors of DMI besides BW. Then, they could revise the nutritional model to include other variables that determine the DMI.

2.4.5 Model refinement (re-starting the process)

Generally, scientists take the second option. In our example, the researcher might go back to their notebook and consider… what other factors could be affecting DMI aside from BW? Eventually, they would develop a new hypothesis, for example: younger, first-lactation animals will consume less than more mature animals with two or more lactations. They plot the data again, including information about the animals' parity:

It appears there is some variation explained by parity. In this way, the researcher can update the model to include other variables, e.g., $DMI = 0.03 * BW + ParityEffect$. Nutritional models with multiple variables are difficult to visualize, but they are conceptually similar to the simpler model in our example.

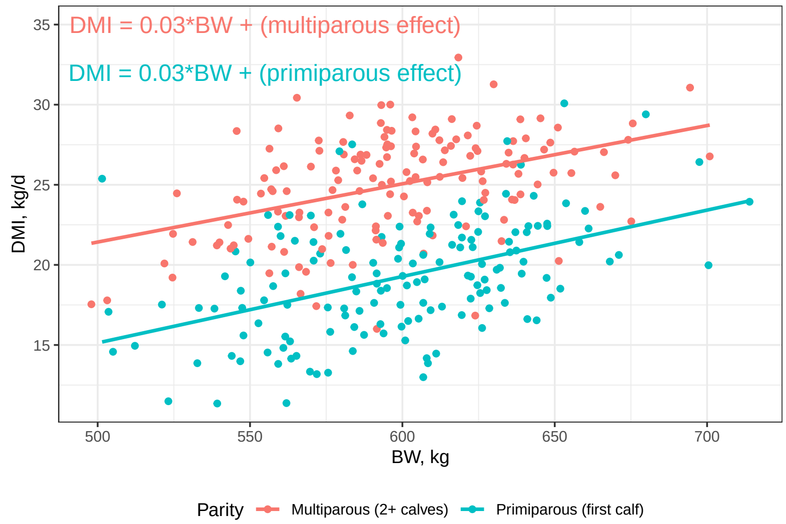

Figure 2.6: DMI vs BW for 300 observations from lactating cows, by parity

2.5 Components of the NASEM (2021) model

Nutritional models such as the NASEM (2021) model contain thousands of variables, related by many types of mathematical expressions. Our simple example used a linear relationship, but nutritional models can also contain non-linear relationships. In our example, the effects of BW and Parity were independent and additive. Most nutritional models also include mathematical terms that describe interactions between variables.

2.5.1 Supplies, requirements, and balances

Most editions of "Nutrient Requirements of Dairy Cattle" have described animal performance in relation to energy and major nutrients such as amino acids, fiber, vitamins, and minerals. The goal of nutritional models is to help producers design diets that support the animal's needs for a healthy, productive life. This involves matching up the nutrients and energy **supplied** by the diet with the amounts **required** by the animal. For a given nutrient, the difference between the amount supplied and the amount required is referred to as the **balance.**

To calculate nutrient supplies, NASEM (**?**) uses primarily information about the feed chemical composition, and some information about the animal and management scenario. From this, it predicts the flows of energy and nutrients that is digestible and metabolizable for the animal.

To estimate nutrient requirements, NASEM (**?**) calculates separate requirements for each different body functions: including requirements for maintenance, activity, growth, reproduction, lactation, and changes in body reserves.

Summing these requirements gives the total requirement for each nutrition. This method for calculating requirements is referred to as a **factorial** approach because it sums the contributions of different factors to determine the total requirement.

The next chapter of this module will discuss the complications associated with estimating nutrient requirements and matching them with nutrient supplies.

2.6 Characteristics of nutritional models

2.6.1 Factorial

2.6.2 Empirical and mechanistic elements

2.7 Nutrient requirement and supplies

Models are machines

2.8 Empirical, mechanistic, and hybrid models

Spectrum of techniques. Empirical refers to models that are verifiable at the level of experience. These models relate inputs directly to outputs.

By contrast, mechanistic models explicitly represent processes that may be difficult to measure. Rather than relating input directly to output, a mechanistic model depicts the mechanisms that lead from input to output.

Input output (empirical) at animal level process explicitly represented and includes more intermediates.

Nutritional models are sometimes described as more empirical or more mechanistic.

More empirical models are based on direct observations of inputs and outputs. By contrast, mechanistic models depict the processes that connect inputs and outputs in greater detail (Hanigan & Daley, 2020)

2.9 Comparing NASEM (**?**) to other dairy models

NASEM (**?**) is one of several dairy cattle nutrition models. In most cases, models are intended to serve as decision support tools. In other words, the model estimates are intended to help dairy stakeholders, especially dairy farm managers, make more-informed decisions. The Cornell Net Protein and Carbohydrate System (CNCPS) is an alternative model upon which commercial ration formulation programs such as AMTS have been built. CNCPS also influence

Robot Cow Moos *and* Gives Milk

Hidden Motors Give Exhibit for World's Fair the Movements of a Living Animal

AN ELECTRIC cow that chews a cud, breathes, moves its head, winks its eyes, moos, and gives real milk will form one of the exhibits at the World's Fair next summer.

This robot animal has just been completed at the New York City workshop of Messmore and Damon, specialists in creating mechanical beasts that range from prehistoric dinosaurs to modern puppies. It is an exact reproduction of a Holstein milk cow, the hide which covers the papier-mache body being that of the real animal. This particular Holstein was chosen as a model because it had a large black spot on one side. In the reproduction, this spot forms a door that can be removed if anything goes wrong with the mechanism inside.

How a single silent electric motor within the cow operates cams and levers to produce the various lifelike movements is illustrated by our artist's drawing. The different-shaped cams vary the speed of the movements of the tail, jaws, head, ears, and eyes to make them more realistic. Forming the support of the head is a flat flexible bronze spring that bends from side to side as the head moves. The sides of the mechanical cow move in and out in regular rhythm to simulate breathing.

A glass milking machine milks the cow, real milk coming from a tank in the udder. Spectators see it drawn through transparent tubes into the glass container. But they do not see a small centrifugal pump, in the pedestal upon which the animal stands, which pumps it back again. The cow cost $3,000.

Drawing, above, of a mechanical cow shows how it is animated by electrically driven motors. Springs in neck give life-like movements to theanimal'shead

Messmore and Damon with the real cow, and, in back of it, the robot that is being made to look just like it

Figure 2.7: This robot cow is NOT a nutritional model. Source: <http://blog.modernmechanix.com>

the development of The Large Ruminant Nutrition System (LRNS) by Texas A&M researchers. In recent years, the importance of evaluating the environmental and economic impacts of dairy production have led to the development of models not just focused on the animal-level variables (as with NASEM), but instead integrating information about the entire farm system. These models, for example, the Ruminant Farm Systems (RuFaS) model, incorporate detailed information about local weather, soil characteristics, crop growth and storage, and prices of feedstuffs.

Some programs allow users to optimize the inclusion rate of selected diet ingredients (e.g., least cost ration formulation; AMTS program). In contrast, NASEM (**?**) is designed to **evaluate** existing diets rather than **formulate** new diets that optimize user-defined parameters or meet user-defined constraints. Additionally, NASEM (**?**) predicts selected environmental impacts at the individual animal, predominantly based on dietary factors. Thus, NASEM (**?**) predictions of environmental impacts do not integrate farm system information to the same extent as other models, e.g., RuFaS.

Other ruminant diet evaluation models

The Cornell Net Protein and Carbohydrate System (CNCPS) https://cals.cornell.edu/animal-science/outreach-extension/publications-resources-software/cncps

The Large Ruminant Nutrition System (LRNS) https://animalscience.tamu.edu/the-utility-of-applied-nutrition-models-a-brief-history-and-future-perspectives/

Ruminant Farm Systems (RuFaS) http://rufas.org

2.10 Conclusion

2.11 Possible additions

Experimentation example (in addition to observation example)

More complex is not always better.

Mechanistic vs. empirical

Remove the 2021 from NASEM? NASEM-8 instead? confusing with software.

It allows users to input target dry matter intake and milk production, or to use prediction equations to estimate the dry matter intake and milk production based on the diet and animal characteristics. This flexibility enables users to run the NASEM Dairy-8 (**?**) model whether they have very detailed information about their herd (e.g., there are records for milk and component production, body weight, dry matter intake, average daily gain) or very limited information about their herd (e.g., there are limited records for input variables).

Chapter 3

Requirements

Learning Objectives

1. Define a nutrient requirement in precise terms.
2. Explain how nutrient requirements are determined through experimentation.
3. List and discuss limitations of typical conceptions of "requirement"

This website is mostly about NASEM

In this we will learn about NASEM. WHat it is. Picture of it. (info from dairy nut req section) But first, detour into history of nutrition models. A brief history. Why use comparing NASEM to others.

3.1 Defining "nutrient requirement"

3.1.1 Requirement definitions in human and dairy nutrition

Previous editions of "Nutrient Requirements for Dairy Cattle" did not explicitly define the term **nutrient requirement**, but NASEM (**?**) includes an entire chapter delineating nutrient requirements and related terms. Much of this work is based on definitions used in human nutrition. NASEM's Food and Nutrition Board in the Institute of Medicine (**?**) defined a series of terms outlining what **nutrient requirement** means in the human nutrition context. The dairy nutrition committee selected from these terms for use with dairy cattle.

The NASEM (**?**) book defines a nutrient requirement as **"the daily amount of a nutrient necessary to meet a healthy animal's needs for maintenance, activity, growth, reproduction, and lactation without any**

changes in body reserves or status" (NASEM, 2021, p. 4). Let's break down each part of this definition.

- **the daily amount of a nutrient -** In human and animal nutrition, nutrient requirements are often given in amounts per day. Thus, a requirement is a rate of amount consumed per unit time. The use of "day" as the denominator is practical. Per hour is too short a timescale, because animals do not *require* nutrients every hour to maintain their health and functioning. Yet per week is too long, because an animal deprived of a certain nutrient would probably show symptoms associated with that nutrient deficiency. Additionally, most cattle rations are mixed and fed once or twice daily, so farm operators need to know the amounts to feed once or twice daily. Therefore, amount per day is a logical choice of timescale for expressing the requirements of most nutrients.

- **a healthy animal's needs -** NASEM (**?**) acknowledges that illnesses alter the physiological state of animals such that they have different nutrition requirements. However, each illness alters nutrient requirements differently. The committee decided that there was insufficient data to predict requirements for unhealthy animals presently. As such, requirements are based on the assumption that the animal is healthy.

- **for maintenance, activity, growth, reproduction, and lactation without any changes in body reserves or status -** This part explains that nutrient requirements are calculated to allow the animal to maintain various body functions without gaining or losing body reserves (e.g., losing fat or muscle mass) or status (e.g., losing milk production). Therefore, a nutrient requirement is specific to a given animal and scenario.

Test Yourself: How is the term **nutrient requirement** used colloquially, and how does this differ from its scientific definition?

3.1.2 Absorbed and metabolizable amounts

Before moving on, we need to add more detail to what is meant by **the daily amount of a nutrient**. We know that not all the energy and nutrients eaten by an animal can be actually used for the body functions listed above. This is because a fraction of the energy and nutrients is excreted in feces and urine, and another fraction is lost as gas and heat. When discussing requirements, NASEM (**?**) most often gives the amount of nutrient on a **metabolizable** basis. This means that when we define the daily amount of a nutrient required, we mean the amount that is actually available for the animal to use for body functions (metabolizable amount) rather than the total amount of intake (gross amount). This will be detailed in later chapters. Reporting requirements as metabolizable amounts applies to energy and most nutrients except minerals, which are considered on an **absorbed** basis. The committee most likely chose an absorbed basis for minerals due to data availability. Many mineral studies report the amount of circulating minerals in the blood (absorbed) and few studies analyze mineral content in excreta (feces and urine).

Just for fun: Check a human food label. Similar to reporting for dairy cattle nutrition, human nutrition labels typically show the amounts of metabolizable energy and nutrients.

3.2 Dietary reference intakes

We established a basic definition for a nutrient requirement. Estimating these average requirements is an important component of NASEM (**?**). But NASEM Dairy-8 (**?**) not only helps determine the daily amount of nutrient required **on average** (the mean), it also gives information about the variability around the average (the variance). As a consequence, the estimated average requirement is just one parameter in a class of terms referred to as **dietary reference intakes**. These dietary reference intakes combine information about both the mean and variance in a requirement to assist nutritionists in formulating rations that protect against under- and over-supplying nutrients.

Dietary Reference Intakes include the estimated average requirement, the recommended daily allowance, adequate intake, and maximum tolerable level. Each of these will be defined in the subsequent sections. The dietary reference intakes are based on the principle that nutrient requirements are not a single fixed level of nutrient intake. Instead, nutrient requirements have both a mean and variance. In other words, a distribution.

NASEM (**?**) explains that within a given group of animals at a particular life stage, the distribution of responses to nutrient intake includes predictable and unpredictable variation. Predictable sources of variation are factors with a known effect on the animal's response to nutrient intake (e.g., stage of lactation, milk production, body weight). Conversely, unpredictable variation represents both random variation and unmeasured variation.

3.2.1 Protecting against underfeeding with "safety factors"

Considering the variance in nutrient requirements is especially important when it comes to avoiding reductions in performance due to nutrient deficiencies. For example, let's imagine we have a population of lactating cows with a distribution of requirements that looks as shown below. We feed them the estimated average requirement (EAR), as shown with the vertical red line:

Test Yourself: What proportion of the population is being underfed if nutrient intake is at the EAR?

When feeding the average requirement, we can see that about half the animals will be overfed, and half will be underfed the nutrient. Underfeeding nutrients is

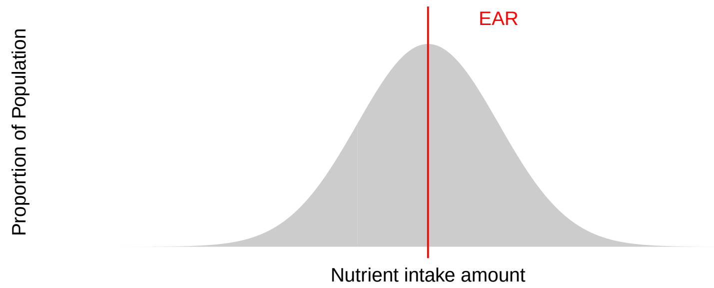

Figure 3.1: Population distribution of nutrient requirements with reference intakes annotated.

expected to worsen health and performance. For this reason, human and animal nutritionists often feed not the average requirement, but instead the average requirement plus a "safety factor." In order to determine an appropriate safety factor, we need to know the variance in the requirement. For example, in human nutrition, the recommended dietary allowance (RDA) refers to the EAR + two standard deviations (recall that standard deviation is a measure of variance).

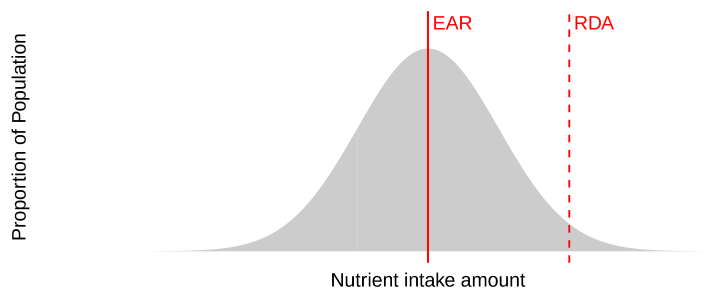

Figure 3.2: Population distribution of nutrient requirements with reference intakes annotated.

Test Yourself: What proportion of the population is being underfed if nutrient intake is at the RDA (EAR + 2 standard deviations)?

Because the RDA is set at 2 standard deviations above the EAR, when feeding at the RDA, only a small proportion (2-3%) of the population is being underfed. The majority (97-98%) of the population is being fed an adequate amount. This illustrates how nutritionists need to know both the mean and variance of a nutrient requirement to make informed decisions about the amount to feed.

3.2.2 Protecting against overfeeding

For dairy cattle, it is often preferable to overfeed nutrients than to underfeed. However, there are risks associated with overfeeding that nutritionists must guard against. For example, overfeeding energy could result in excessive body reserve gain leading to an increased risk of ketosis. Overfeeding the mineral selenium can cause acute toxicosis. Overfeeding crude protein is associated with reduced reproductive performance and (_______________citation) and an increase in negative environmental impacts.

In cases where toxicities have been observed and adequate data are available, NASEM (**?**) provides the **maximum tolerable level (MTL)** of a nutrient. At the MTL, research has shown that symptoms of toxicity begin to occur. Vary in requirement. Keeping in mind that feeds vary in composition and animals vary in their requirements, nutritionists should aim to create rations that are sufficiently below the MTL to reduce the chances of toxicities.

3.2.3 Accounting for uncertainty

Finally, NASEM (**?**) acknowledged that there are certain cases where insufficient data are available to determine the mean and variance for a nutrient requirement. In these cases, the committee makes an educated guess on an appropriate level for the nutrient requirement. The best guess for the requirement is referred to not as an EAR, but instead as an **adequate intake (AI)**. This distinction helps nutritionists determine whether the requirement has been determined after substantial experimental studies (EAR) or whether the requirement is an educated guess by the committee (AI).

Putting it all together, we can see all of the dietary reference intakes discussed so far:

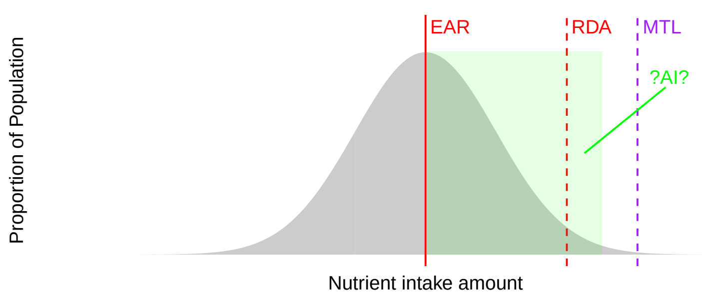

Figure 3.3: Population distribution of nutrient requirements with reference intakes annotated.

Test Yourself: The figure shows several reference intake levels. What does each mean, and when might it be useful?

3.3 Modeling nutrient requirements and supplies

We established that nutrient requirements need to be considered as the absorbed or metabolizable amounts of nutrients in the intestine. Yet typically, nutritionists only have information about the nutrients in the feed before it enters the animal's mouth.

This raises two questions, both of which are answered by nutritional models...

1. Assuming we know the composition of the diet as it is fed, and we know about the animal we are feeding, how do we know the amount of nutrient that will be absorbed or metabolizable at the intestine?
2. How do we know what absorbed or metabolizable amount of nutrient is required for various body functions (e.g., maintenance, gestation, lactation, growth, and reserve gain)?

Nutritional models such as NASEM (**?**) address the first question by tracing the **supplies** of nutrients through the processes of digestion and absorption. Based on the chemical and physical properties of a diet, nutritional models can predict how it will be digested, what nutrients will be absorbed at the intestine, and what nutrients will be available for metabolism.

This is based on experiments where a given diet was fed to a group of animals with certain characteristics, and the amounts of nutrient digested was measured at various locations, e.g., ruminally, duodenally, fecal excretion. post-ruminal digesta, duodenal digesta, fecal excreta, urine excreta, gas emissions.

For the second question, nutritional models such as NASEM (**?**) use aggregated data from previous experiments to draw a connection between the absorbed or metabolizable supply of a nutrient and its effects on animal performance. Therefore, nutritionists who know the absorbed or metabolizable amount of a nutrient can compare

In the second question, there is a HUGE assumption made - that milk production only happens above and beyond maintenance and other functions. THis applies to the broken stick and curvilinear method for determining requirements.

Measured size of fetus and uterus. Constitutive

With certain functions, we need to maintain performance without causing symptoms of a deficiency or excess. e.g. maintenance. This is also because we have tons of data on milk but reproductive performance is harder to measure.

With lactation, though, the response will increase.

Determining the nutrient required for each separate function. Some empirical data, and some theoretical depictions. Maintenance figured out with crazy experimental techniques like examining the calorie expenditure of animals with no feed intake. Or by labeling elements to determined the endogenous secretions.

Scurf. Gestation estimated growth and reserve gain estimated from composition of slaughtered animals.

The second question is less straightforward because we have various concepts of requirements. Requirements for maintenance, gestation, and growth are more straightforward. Nutritional models assume that the the makes milk AFTER meeting maintenance and other needs, which is not.

A complete nutritional model helps build an entire picture.

If we know the chemical composition of feeds entering the animal's mouth, h

Because requirements are interpreted as metabolizable or absorbed amounts, nutrient requirement models such as NASEM (**?**)

3.4 Types of literature used by NASEM (?)

We know now that a nutrient requirement is the daily (metabolizable or absorbed) amount of a nutrient required to support an animal's body functioning without changing body reserves and status. We also know that requirements are often calculated factorially, e.g., separate requirements are estimated for maintenance, gestation, lactation, growth, and reserve gain and summed together to estimate the total nutrient requirement.

Yet how does NASEM (**?**) determine the required nutrient needed for separate body functions? The committee uses a variety of types of research. The narrative in NASEM (**?**) focuses on research done after the 7th edition (NRC, 2001), but it also cites some classical studies done in prior years. Some examples of the types of literature referenced by NASEM are discussed below.

3.4.1 Measuring body composition

**** citation **

Nutrient requirements for growth and changes in body reserves are often estimated using data on body composition. For example, early researchers determined the chemical composition of the carcasses of animals slaughtered at different ages. They assumed that 1 kg of growth in the body frame (carcass) would require at least as many nutrients as were contained in 1 kg of the body frame at slaughter. Similarly, studies have measured the composition of cows with more or less body reserve (body reserves = primarily adipose and muscle tissue). This type of research is often used to calculate nutrient requirements expected for certain rates (kg/d) of growth and changes in body reserves.

Researchers in the mid-20th century studied the chemical composition of the gravid (pregnant) uterus, including the fetus, placenta, and the uterus itself. They tracked the growth of the gravid uterus across the gestation period. This type of research helped determined nutrient requirements for gestation, often based on the gestational age (days pregnant) and the expected weight of the calf.

3.4.2 Measuring losses when intake is minimal

?

To determine maintenance requirements, one experimental approach involves feeding animals very little of the nutrient in question for a short period. Then, researchers can determine the amount of nutrient that would be lost (in urine and feces) through body functions alone (not diet). For example, part of the maintenance requirement for protein is the amount of protein lost in feces due to typical gastrointestinal tract secretions and sloughed cells. This fraction is referred to as metabolic fecal protein. Typically, the protein in feces includes both metabolic fecal protein and undigested dietary protein. When minimal protein is fed, the amount of undigested dietary protein approaches zero. This isolates the amount of metabolic protein needed by the animal. A similar approach is used to determine the energy, protein, and minerals lost in urine as part of maintenance body functions.

3.4.3 Studying symptoms of deficiency and toxicity

** citation **

The NASEM (**?**) committee also used studies that reported observable symptoms of deficiency and toxicity. For example, vitamin D deficiency (rickets) is known to cause a stiff gait, bowed legs, and increased incidence of fractures. By studying the levels of absorbed vitamin D that were associated with visible symptoms, the committee could establish minimum nutrient requirements. Conversely, the committee set upper limits by examining the level of nutrient associated with symptoms of toxicity. This approach was particularly important with vitamin and mineral requirements.

3.4.4 Regression on productive performance

** citation **

Finally, the NASEM (**?**) committee cited several works where requirements was studied with a regression approach. When data are abundant, regression enables researchers to mathematically relate values of a nutrient (X) to an animal performance trait (Y). For example, milk and milk component data are often used as dependent (Y) variables in regression. This is because nearly every study with dairy cattle measures the production of milk and components.

For many people, regression calls to mind the image of a line. Perhaps in high school, they learned that a line can describe the relationship between X and Y variables by an intercept and slope. The regressions cited by NASEM (**?**) uses a similar idea. However, the relationship between the metabolizable amount of a nutrient (X) and animal performance (Y) is generally not expected to be a single line. Two common shapes are given below.

3.4.4.1 Breakpoint analysis or "broken-stick" response

?

Assuming the same animal and diet characteristics, one way researchers have conceptualized requirements is through breakpoint analysis. With this framework in mind, researchers examine the performance response (e.g., the production of fat- and protein-corrected milk, FPCM) with increasing metabolizable amounts of nutrient X. The requirement is expected to be the "breakpoint" where additional amounts of nutrient (X) lead to zero gains in performance (Y). Breakpoint analysis is sometimes referred to as a "broken-stick" model, because it resemble a stick of wood that has been snapped. More technically, it is a piecewise linear function.

The breakpoint or broken-stick model supposes the following:

Feeding more nutrient X will increase FPCM production if nutrient X is deficient. Feeding above the requirement for nutrient X will result in no gains in FPCM (response = 0).

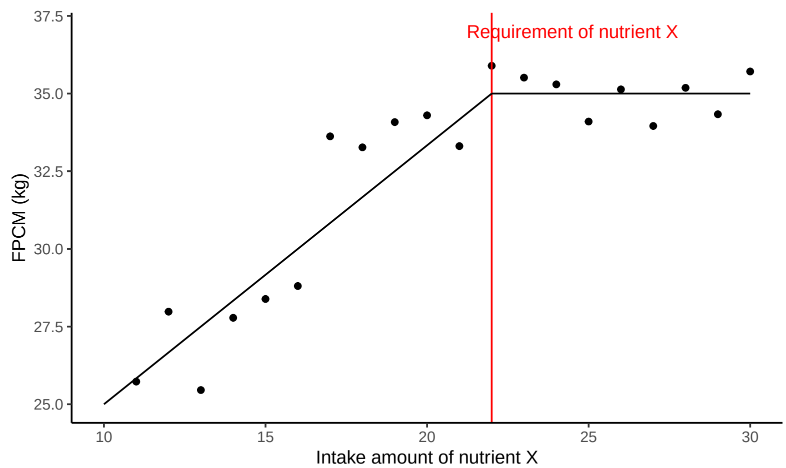

Figure 3.4: Broken-stick response to nutrient X metaboliazble amounts

3.4.4.2 Curvlinear response

?

Sometimes, the broken-stick type response does not match well with the observed data. This can be because excessive amounts of the nutrient X lead to declines in performance Y, rather than Y remaining flat. Or perhaps the relation between X and Y may appear to be made up of curves rather than lines. In these cases, we can express the relation of X and Y using mathematical terms for curves. For example, polynomial functions, e.g., $FPCM = 25 + 12x - 0.1x^2$ can describe a gradual increase in performance that curves to reach a maximum and declines. A logistic function can describe a situation where additional metabolizable amounts of nutrient X result in smaller and smaller gains in performance (Y). Various mathematical functions are used "behind the scenes" in the NASEM Dairy-8 (**?**) nutritional model, and they are based on regression work.

In general, nutrient requirements are determined by experiments where different levels of a nutrient are fed and animals' responses (e.g., bodyweight, milk production, reproductive performance) are observed. Let's consider a hypothetical nutrient X. A single experiment might compare just a few levels of nutrient X and record the average response. For example, researchers could feed 0.9, 1.2, and 1.5% of diet dry matter as calcium and record the response with each level.

Over time, more experiments are done. The data from multiple experiments can be combined through meta-analysis. Compared to an experiment that shows responses to just a few levels of nutrient X metabolizable amounts, a meta-analysis can show animal responses across a large range of nutrient X metabolizable amounts. Using data from the meta-analysis, researchers can plot animal performance at each level of nutrient X intake to determine the nutrient requirement for a given scenario.

Test Yourself: Assume you have the data to plot the volume of milk production (Y) at different levels of the metabolizable amount of nutrient X. How would you determine the required amount of nutrient X for each level of milk production?

This type of curve can be described mathematically with an intercept plus positive linear and negative quadratic terms. e.g., for nutrient X,

In NASEM, Calculate the derivative and set it equal to zero. This will give us the maximum, where the rate of change in FPCM is 0, before it starts decreasing.

Positive linear and negative quadratic.

3.5 Activities

Formulate a diet Create a timeline of NASEM and NRC models and significant updates within each edition. The front matter of each book specifies updates. Third party sources such as conference proceedings may also give some hints.

Let's consider a non-nutritional example of a mathematical model. I noticed that I have to fill up my car's 12-gallon gas tank every 300 miles. From this information, I can calculate the miles my car will travel (output) based on the gas provided (input), 25 miles per gallon. I can summarize this with a mathematical model:

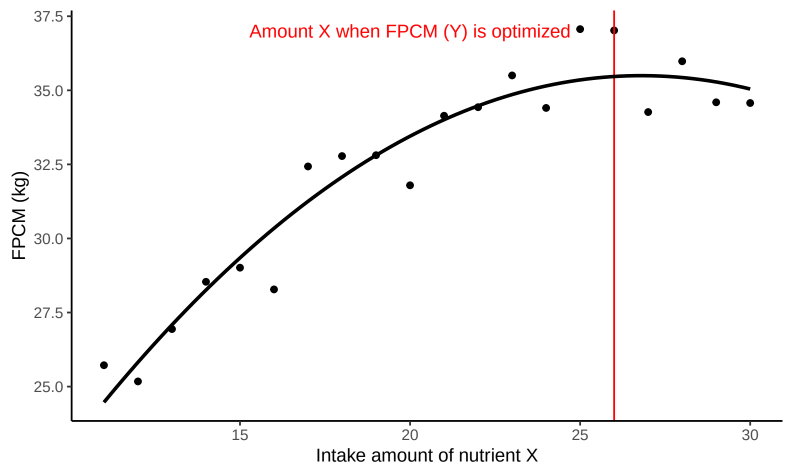

Figure 3.5: Curvilinear response to nutrient X metaboliazble amounts

$$M = 25 * G$$

Where M is the miles traveled and G is the gallons of gas input

If I "feed" my car 10 gallons of gas, how far will it travel? We can use the model to predict:

$$M = 25 * 10M = 250$$

This is a simple input-output model that doesn't predict the processes involved. However, we could modify the model to make it more accurate. We can split my car's performance into categories… miles in town (M_T), or miles on the highway (M_H). As is typical, my car gets slightly better gas mileage on the highway as compared to in town. We can use a model to describe the average performance.

$$M = M_H + M_T M_H = 30 * G M_T = 20 * G$$

Let's say I traveled 20 miles in town and 120 on the highway, and I recorded my car's actual gas usage at 5.3 gallons. Is my gas usage above or below what I would expect based on the model?

Answer - gas usage is more than the expected amount (5 gal)

Which model is more empirical?

Which model is more mechanistic (shows the processes)

avoided using the term EAR.

For this reason, nutritionists have devised quantities beyond just the average requirement. MTL,

Sometimes it is more dangerous to overfeed

When discussing nutrient requirements, it is important to remember that feeding too much or too little.

For this reason we care about variance in requirements.

Nutrient requirements can be expressed

When discussing nutrient requirements, it is important to remember tha

The NASEM (**?**) book defines a nutrient requirement as **"the daily amount of a nutrient necessary to meet a healthy animal's needs for maintenance, activity, growth, reproduction, and lactation without any changes in body reserves or status"** (NASEM, 2021, p. 4). Let's break down each part of this definition.

Nutrient requirements represent averages

Nutrient requirements are often discussed as fixed quantities. For example, we might say that a lactating cow requires

An additional complication to nutrient requirements

measurement error, stage of lactation, milk production, body weight,

Much of the variation in nutrient requirement depends on measured characteristics of the animal, i.e., the same information users typically enter as NASEM (**?**) inputs. This is predictable variation in requirement. However, even after removing the known sources of variation, individual animals still have slightly different requirements.

For example, let's consider 10,000 hypothetical cows with exactly the same bodyweight, same production status, and same NASEM (**?**) input variables. If we enter all of this information into the NASEM model, it predicts that these 10,000 cows have exactly the same nutrient requirement. However, nutrient requirements have both deterministic (predictable) and stochastic (random) elements. In other words, we expect that the true population "requirements" are not a fixed value (e.g., 40), but instead are distributed in a bell-shape (e.g., 40 $\pm$ some measure of variation).

For this reason, NASEM (**?**) has begun to express requirements not just as the mean requirement, but also with a measure of variation.

NASEM (**?**) is somewhat unclear about the specificity of a nutrient requirement. Based on the definitions given for humans specific to "gender and life stage", it appears NASEM definitions may apply within breed (e.g., Holstein, Jersey) and class (e.g., lactating cow, dry cow,)

which predictable variation is

the analogies drawn to the "gender and life stage"

3.5.0.1 Measurement error in diet composition - we are measuring average.

We do not have ALL NASEM inputs measured with each study, but the major ones are known. From this logic, we would take two dairy cattle with similar life stage (e.g., two heifers)

On the human side, requirements are given specific to gender and life stage. These are not the only variables affecting nutrient requirements that we know about. However, they are measured in most studies.

for a given nutrient, if we plotted the actual requirements of 10,000 hypothetical cows

Actual Requirements for selected cows with the same measured input variables. Cow 5409: 35 Cow 9874: 42 Cow 6738: 37

3.5.0.2 Energy and nutrient-allowable production