Please do not write on this; Return it in good condition. Write your answers on a separate sheet of paper.

5

Introduction to Nutrition

Key Terms

Applied or production nutritionist
Ash
Balance trial
Basic nutritionist
Bomb calorimeter
Carbohydrates
Cellulose
Crude fiber
Crude protein
Diet
Digestibility
Digestion trial
Dry matter
Energy
Estrous cycle
Ether extract
Fats
Feed
Feed analysis
Feeding trial
Feedstuff
Finishing
Growth
Maintenance
Metabolism trial
Minerals
Monogastric
Nitrogen-free extract (NFE)
Nutrient
Nutrient requirement
Nutrition
Palatability
Production
Protein
Ration
Reproduction
Ruminant
Van Soest fiber analysis
Vitamin
Work

Learning Objectives

After you have studied this chapter, you should be able to:

- Define nutrition and understand the reasons for studying nutrition.
- Explain what a nutrient is and know the difference between dietary essential and nonessential nutrients, classify the nutrients, and list the 50 dietary essential nutrients.
- Describe the general uses of nutrients in the body and discuss the major factors that affect an animal's needs for nutrients.
- Explain in detail the three major types of animal trials that nutritionists use.
- Define and explain feedstuff analysis.
- Summarize the feeds evaluation procedures described in this chapter.

INTRODUCTION

Nutrition is the study of how the body uses the nutrients in feed to sustain life and for productive purposes. Nutrition is a very complicated science. To study nutrition adequately, we must study the nutrients and consider how animals consume, digest, absorb, transport, metabolize, and excrete them. We must further consider how the body uses nutrients for productive purposes, and then consider the economics of feeding and the potential effects to the human population of various feeds, additives, medicinals, and so on. Good nutrition is basic to good health and production.

Nutrition The study of the body's need and mechanism of acquiring, digesting, transporting, and metabolizing nutrients.

In commercial livestock production, it is important to study nutrition to be able to feed livestock cost effectively. Depending on the type of enterprise, the cost of feed and feeding is 45–75% of the total cost of livestock production. You cannot make money in animal production agriculture without properly feeding the livestock.

The study of nutrition is important for several other reasons. Nutrition affects general health and well-being, physical abilities, and susceptibility to and ability to recover from disease. Nutrition is also an intricate part of many body systems. If we understand nutrition, we can understand those systems. Studying nutrition provides an excellent opportunity to understand the basic "bio-logic" of life—you cannot understand nutrition without understanding the basis of life, and you cannot understand the basis of life without understanding nutrition.

The field of nutrition is broad and encompasses much information: nutritionists thus need to specialize. This specialization allows the individual nutritionist to keep up with the rapidly changing industries and the rapidly advancing science. Specialty areas for animal nutritionists are divided into two categories, based on whether the animals studied are monogastric or ruminant. **Monogastric** nutritionists focus on one-stomached animals such as poultry, swine, horses, dogs, cats, fish, rats, mice, guinea pigs, monkeys, and some zoo animals. **Ruminant** nutritionists specialize in sheep, goats, dairy/beef cattle, and other wild or captive species that have a rumen. Most nutritionists tend to fall into one or the other of two additional camps: **basic nutritionists** or **applied/production nutritionists**.

Monogastric Having only one stomach.

Ruminant Hooved animals that have a rumen and chew their cud.

Basic nutritionist A nutritionist interested in elucidating basic metabolism and nutrient action and interaction.

Applied or production nutritionist The practical nutritionist. An applied nutritionist works on practical questions such as cost effectiveness, method of delivery, and carcass effects.

Basic nutritionists study the metabolism of the animals, and they are most interested in the biochemical mechanisms of nutrient metabolism. They are sometimes concerned with knowledge for its own sake rather than practical applications. What basic nutritionists learn is important to production nutritionists, who take the basic nutritionists' findings and determine real-world applications. Applied or production nutritionists are more interested in maximal, cost-effective feeding of animals in a production setting. They explore the many possibilities for using feedstuffs in the best possible way to make money. Often thought of as "feed-em and weigh-em" research, applied nutrition is really a complicated and often challenging attempt to translate basic science into real-world application. We often find nutritionists who bridge several categories or even defy categorization. Even a specialist must know something about several disciplines in order to be a good nutritionist. These disciplines include biochemistry, cytology, economics, marketing, endocrinology, genetics, inorganic chemistry, mathematics, microbiology, neurology, organic chemistry, physics, physiology, veterinary medicine, and waste management.

NUTRIENTS AND THEIR USES

Nutrient A substance in the diet that supports the normal functions of the body.

If we are to understand nutrition, we must understand **nutrients**. Nutrients are substances required for life processes. They are used in body metabolism to maintain the body and for reproduction, growth, and lactation. Nutrients provide energy and building material for the body, as well as metabolic regulators. Nutrients are classified as either dietary essentials or dietary nonessentials. Dietary essential nutrients must be a part of the diet. The nutrient classifications are water, carbohydrates, vitamins, minerals, proteins, and fats (lipids). Energy is needed by the body but is not a nutrient per se. Carbohydrates, proteins, and fats all provide energy to the animal through their breakdown products. Figure 5–1 lists the 50 dietary essential nutrients.

Water is frequently neglected in many discussions of nutrition. This seems odd, considering that the body will die more quickly from water deprivation than from the deprivation of any other nutrient. Water is used by the body as a lubricant; as a regulator of body temperature; as a solvent for the body's solid components; as a

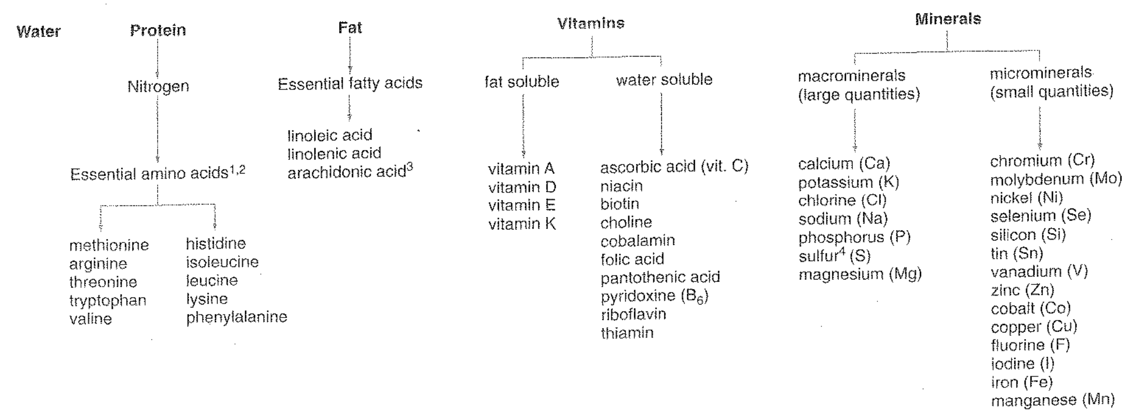


Figure 5–1

The essential nutrients.

[1]Mnemonic device for remembering essential amino acids = MATT HILL VP.

[2]For poultry, two additional amino acids are needed: glycine and proline.

[3]Arachidonic acid can be synthesized from linoleic acid if it is available, so it is only essential if linoleic acid is absent or in short supply.

[4]Authors vary on whether or not to list sulfur as a macromineral or micromineral. The discrepancy arises because only a very small amount of inorganic S is needed, but the sulfur-containing amino acids (organic S) are needed in larger quantities.

Figure 5–3
Finishing cattle for slaughter involves feeding for maintenance, growth, and fat deposition. (Photo by Brian Ptechtel. Courtesy USDA-Agricultural Research Service.)

Production The general term used to describe the output of usable products and services by animals.

Work Physical exertion as a production function.

Production refers to the output of products such as eggs, milk, and wool. The nutrients needed for production vary with the product. Lactation is the most demanding of all the production functions in mature animals. Milk contains water, protein, fat, vitamins, and minerals, and additional energy is required to produce it. Eggs contain protein, fats, minerals, vitamins, and water. Diets must be selected and rations must be balanced for these nutrients to accomplish cost-effective feeding. Other types of production require levels of nutrients specific to the product or combination of products being produced (Figure 5–4).

Work is a specialized production function and the major product of some species such as working horses, working dogs, and packing llamas (Figure 5–5). The major nutrient increase needed for work is energy. Carbohydrates are generally the most cost-effective means of increasing energy in the diet, so carbohydrate-rich feeds are generally used to meet this need.

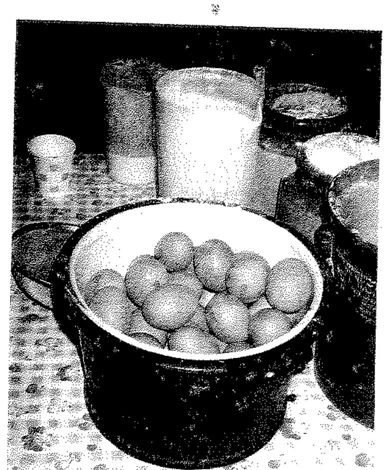


Figure 5–4
Production of eggs, milk, and wool requires levels of nutrients specific to the product being produced.

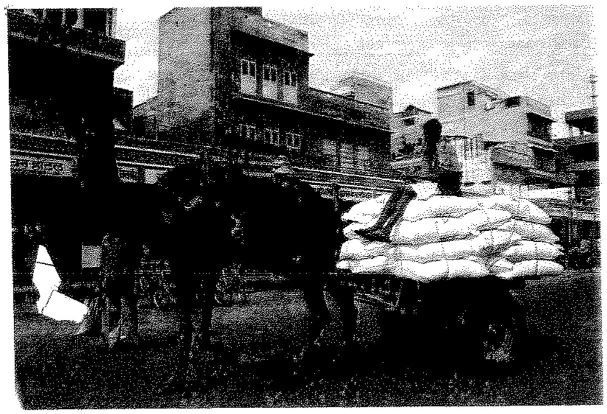


Figure 5–5
Work is a specialized production function that requires additional energy in the animal's diet. (Photo courtesy of Paige Rabalais. Used with permission.)

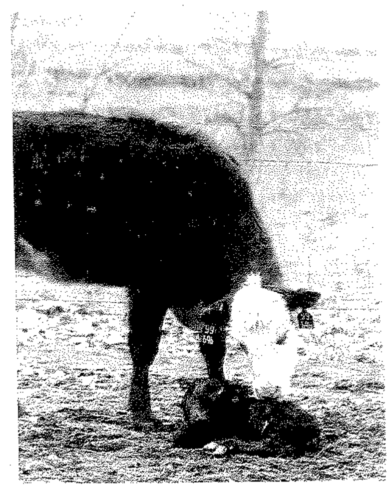


Figure 5–6
This 2-year-old beef cow must provide milk for her newborn calf, rebreed, and gestate her next calf, all while still growing. (Photo by Scott Bauer. Courtesy USDA-Agricultural Research Service.)

Reproduction of live normal offspring is a basic biological necessity for a species to survive. For efficient, cost-efficient agriculture, we must provide for the arrival of a new generation at the same time we are receiving the products from the current one. Providing adequate nutrition for the reproductive function must be accomplished in addition to maintenance and production. Poor nutrition can be manifested in abnormal or delayed **estrous cycles**; reduced calf and lamb crops; small and weak litters in swine, dogs, and other litter-bearing species; and poor egg production and/or hatchability in poultry. The high-producing animals are often the ones with whom we have the most difficulty. The third trimester of a pregnancy is the most critical for the reproducing female (Figure 5–6). Energy and protein must be increased, and the need for several minerals and vitamins is increased during this period as well.

Reproduction The combined set of actions and biological functions of a living being directed at producing offspring.

Estrous cycle The time from one period of sexual receptivity in the female (estrus or heat) to the next.

FEED ANALYSIS

Properly feeding livestock requires knowledge of the nutrients found in the feedstuffs available and balancing of these nutrients to meet the physiological needs for the species in question. A comprehensive evaluation procedure discovers nutrient

Digestibility A measure of the degree to which a feedstuff can be chemically simplified and absorbed by the digestive system of the body.

Palatability The acceptability of a feedstuff or ration for consumption.

Feed Foods used to feed animals.

composition, **digestibility**, productive value, **palatability**, and the physical or handling characteristics of **feeds**. Feeds analysis also provides useful information about feed growing, harvesting and storing methods, thus helping to obtain the highest quality feed for the animals and the most profit to the producer (Figure 5–7).

Three basic types of analytical methods are commonly used to analyze feeds for nutrient content. *Chemical procedures* are standard chemistry applied to feeds. *Biological procedures* use animals to test the feeds. This is more time consuming, labor intensive, and expensive but gives a better estimate of how the animal will use the feed. We also use some species of animals as models for other species to save money (i.e., rats for pigs). *Microbiological procedures,* the third type, are similar to biological procedures but use bacteria in place of higher animals.

Proximate analysis is a set of chemical/analytical procedures designed to partition feedstuffs into water, ash, crude protein, ether extract, crude fiber, and nitrogen-free extract. Although proximate analysis is the most common set of chemical tests used on feedstuffs, the information it provides is sometimes misleading or even inaccurate. However, proximate analysis is still used and will continue to be used. Thus, good nutritionists must learn its limitations as well as its value.

Dry matter Everything in a feed other than water.

Dry matter is determined by heating a feed sample until all water has evaporated. The percentage of the sample that is not water is then referred to as the dry matter of the sample. To balance a ration properly and know how much of each ingredient to mix into a ration, the dry matter must be determined.

Ash The mineral content of a feed.

Ash is considered the mineral content of the feedstuff. It is determined by burning a dry sample in a very hot oven (500–600°C) to burn off all of the organic matter. The actual value in knowing ash content is marginal. However, we mu[illegible] know how much ash is in the feedstuff to make other calculations. In some f[illegible], ash content can be quite high. More detailed mineral analyses are needed to help the nutritionist balance a ration for the various minerals.

Crude protein An estimate of protein content obtained by multiplying the nitrogen content of a substance by a factor, usually 6.25.

Crude protein (CP) is determined by the Kjeldahl process, which isolates and measures the nitrogen in a feed. An average protein contains 16% nitrogen. Crude protein can then be calculated by multiplying total nitrogen by 6.25. As

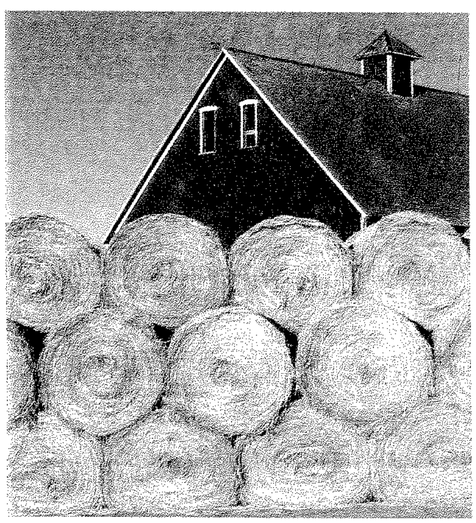


Figure 5–7
Feeds analysis is used to discover nutrient composition, productive value, palatability and physical/handling characteristics. It can also be used to help improve feed harvesting and storing methods. (Photo by Scott Bauer. Courtesy USDA-Agricultural Research Service.)

the name implies, this is a crude measure of nutritional value. Any nitrogen found in the feed is called crude protein. The crudeness of the measurement is not much of an issue for the functional ruminant, which can use nitrogen that is not in protein form (**NPN**) to make real protein in the rumen. For monogastric and immature ruminants, crude protein has less value because amino acid content is the information needed. Modern analytical techniques may soon make this laboratory procedure obsolete.

To determine **ether extract** (EE) (fat), a dry feed sample is extracted with diethyl ether. The ether extracts the fat. Unfortunately, some plant materials other than fat are also ether soluble. These include many organic compounds such as chlorophyll, volatile oils, resins, pigments, and plant waxes that have little nutritional value. The goal of the test is to isolate the portion of the feed that has caloric density. The value of the results depends on the feed being analyzed.

Carbohydrates (CHO) are not determined by direct analysis. For the sake of analysis, carbohydrates are considered to be measured in two fractions: (1) **crude fiber** (CF) and (2) **nitrogen-free extract (NFE)** or nonfiber carbohydrates. The crude fiber procedure is an attempt to simulate digestion in the true stomach and the small intestine. Crude fiber is made up of cellulose, hemicellulose, and insoluble lignin. Nitrogen-free extract is determined by subtraction rather than by a direct chemical method. There is no extract, per se, which makes this method confusing and sometimes hard to understand. The water, ash, crude protein, fiber, and fat found in the feed are added together and subtracted from the number 100. In theory, NFE should be the readily available carbohydrates, such as the sugars and starches. In reality, because it is derived from subtraction, it contains the errors of all the analyses and is generally considered to contain some hemicellulose and lignin. The error is especially true of forages that contain more of these materials. The most problematic limitations to the proximate analysis system are with crude fiber and NFE fractions. Sometimes NFE is less digestible than CF, especially for forages. This discrepancy would not happen if the individual tests were actually measuring what they should be. Because carbohydrates are such a large portion of animal diets, and the different species have very different capabilities of using the different carbohydrates, this shortcoming in the proximate analysis system is a major problem.

The Van Soest method is an alternative fiber analysis (Figure 5–8) that was developed as a means of better describing forages in response to the limitations of proximate analysis. The cell content is almost completely digested by the ruminant, but the cell wall is highly variable in its digestibility by the animal. Much of this variation can be explained by the species of plant and the stage of maturity. The Van Soest method has several uses. It can be used to predict the intake and digestibility of feedstuffs by animals and is a means of evaluating heat damage in forages.

Vitamins must be assayed individually. Biological assays are used for some; others are determined by chemical analysis.

The *determination of the energy content* of common feedstuffs is a very important part of nutrition. An instrument called a **bomb calorimeter** is used to determine the gross energy content of feedstuffs. Gross energy is expressed in **calories**. Gross energy itself has little value, but it is useful in calculating other values. For example, if we know how much gross energy is in both feed and feces, we can calculate how much was digested and absorbed.

Other methods of feed analysis are also used, and more are sure to be developed, to help the nutritionist. For example, infrared light rays are being used for feed analyses. Moisture, lipid, protein, and fiber contents are frequently determined this way, although calcium, phosphorus, salt, and a few other ingredients are also

NPN Nonprotein nitrogen. Any nitrogen found in a feedstuff that is not part of a protein molecule.

Ether extract In proximate analysis, the portion of a sample removed by extraction with a fat solvent such as ethyl ether.

Crude fiber In proximate analysis, the insoluble carbohydrates remaining in a feed after boiling in acid and alkali.

Nitrogen-free extract (NFE) In proximate analysis, a measure of readily available carbohydrates calculated by subtracting all measured proximate components from 100.

Bomb calorimeter A device into which a substance can be placed and ignited under a pressurized atmosphere of oxygen.

Calorie A measure of food energy. The heat required to raise the temperature of 1 g water from 14.5° to 15.5°C. About 4.2 joules.

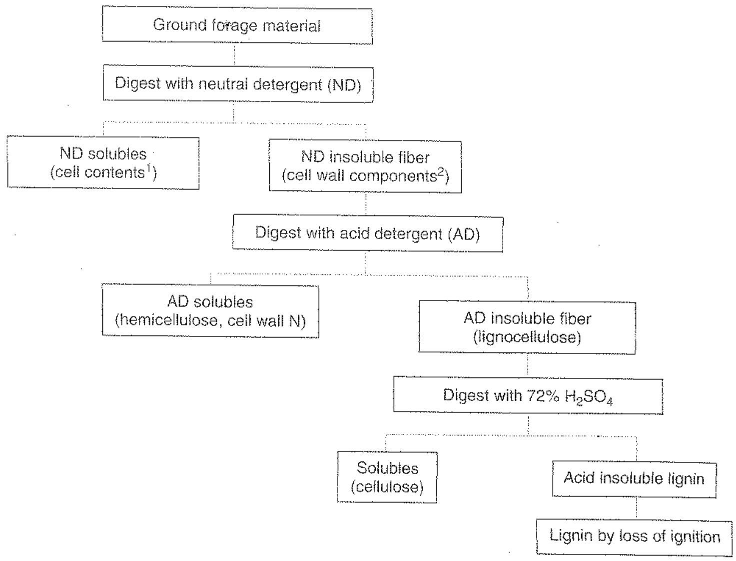


Figure 5–8
Flow diagram for Van Soest fiber analysis.
[1]Cell contents include sugar, starch, soluble carbohydrates, pectin, protein, NPN, lipids, and miscellaneous vitamins.
[2]Cell wall components include cellulose, hemicellulose, lignin, silica, and heat-damaged protein.
(Source: Jurgens, M. H. 1993, p. 58. Used with permission.)

determined. This type of analysis has the major advantage of being much quicker than other methods. However, calibrating the machine requires a wide variety of samples of a wide variety of feeds. Cost is also a problem because instruments are expensive.

Determining the Value of Feedstuffs to Animals

Feedstuff Any substance used as animal feed.

Feeding trial A comparatively simple experimental tool in which animals are fed to determine their performance on specific feeds or substances added to feeds.

Digestion trial An experimental tool used to determine the digestibility of a specific feedstuff, nutrient, or ration.

Metabolism trial An advanced form of digestion trial that measures the body's use of nutrients.

Although chemical analysis of feed is important, it is only one step in determining the value of a **feedstuff** to animals. We must combine the chemical analysis with information about how feed affects the animal. To do this, we conduct trials in which the animal is fed the feed in question. Three major types of animal trials are used: **feeding trials**, **digestion trials**, and **metabolism trials**.

Information gathered from these types of trials allows us ultimately to develop feeding standards and recommendations for feeding animals at different levels of production. Many factors affect nutrient utilization of feeds by animals, including species of animal and type of digestive tract, age, physiological state, (pregnant, growing, lactating, and so on), physical form of the feed (pelleted, cracked, steamrolled, and so on), nutrient balance, and many more. In general, the types of trials used to determine the value of feeds are the same from species to species, with only minor changes in procedures needed.

A feeding trial is used to determine if animals will eat a feedstuff and how they will perform on the feedstuff. It doesn't tell us why things do or don't happen. It only tells us what happens. Common types of feeding trials include growth trials, lactation trials, egg production, endurance (for horses), or even measurement of some specified body function (sperm count, bone levels of calcium, and so on).

Digestion trials are used specifically to discover the degree to which a feedstuff is digested and absorbed by the animal. Digestion trials can be conducted on any nutrient in a feed. In a digestion trial, we feed a feedstuff or diet that has been chemically analyzed to determine its nutrient makeup. During the feeding period, we collect the fecal matter. The fecal material is then analyzed to determine chemically the nutrients that remain in it. We then calculate a digestion coefficient by taking the difference in the nutrients fed and then excreted and calculate a percent disappearance. Digestion coefficients can be calculated for all nutrients. The terms *digestion coefficients* and *percent digestibility* are identical in meaning. The following formula is used to calculate digestion coefficients:

$$\text{Nutrient digestibility (\%)} = \frac{\text{Nutrient intake} - \text{Nutrient in feces}}{\text{Nutrient intake}} \times 100$$

The basic procedure for calculating a digestion coefficient is given in the following example:

During a digestion trial, a steer ate 88 lbs of hay. The hay was 11.8% crude protein. The digestion trial was 7 days long. During the trial, the steer excreted 203 lbs of feces, which were analyzed and found to contain 1.3% protein.

1. Calculate a digestion coefficient for the protein in the hay.

$$\text{Protein digestibility} = \frac{\text{Total protein consumed} - \text{Total protein excreted}}{\text{Total protein consumed}}$$

$$= \frac{(88 \text{ lbs} \times 11.8\%) - (203 \text{ lbs} \times 1.3\%)}{(88 \text{ lbs} \times 11.8\%)} \times 100$$

$$= \frac{10.38 - 2.64}{10.38} \times 100$$

$$= \frac{7.74}{10.38} \times 100$$

$$= 74.6\%$$

2. Calculate the digestible protein content (DP) of the hay:

$$\text{DP} = \text{Crude protein content} \times \text{\% Digestibility}$$

In this example, the crude protein content of the forage is 11.8% and the digestibility of the protein is 74.6%. Therefore, 11.8 × 74.6 = 8.8 DP in the hay.

TDN (total digestible nutrients) is a measure that historically was used extensively to balance rations for livestock. It is considered to be the digestible energy content of a feed expressed in terms of a carbohydrate equivalent basis. TDN is calculated using digestion coefficients for the crude protein, ether extract, crude fiber, and NFE portions of a feed sample. Only the energy-containing components (not water or ash) are included. The basic procedure for calculating TDN is indicated by the following example:

Fraction	Amount in Feed (%)	×	Percent Digestibility	=	Contribution to TDN (%)
Crude protein	10	×	75	=	7.5
Ether extract	5	×	80 × 2.25	=	9.0
Crude fiber	5	×	60	=	3.0
NFE	70	×	90	=	63.0
			% TDN in feed	=	82.5

Note: One of the most confusing problems for some students is how to handle the decimal point. When you multiply a percent × a percent and you want your answer in a percent (as in the TDN example), move the decimal two places to the left on only one number (either one), and your decimal will then be where you want it to be in your answer.

Expressing Feed Composition on a Dry-Matter (DM) Basis

The nutrient contents of a feed are commonly expressed on either an air-dry (as-is) basis or a dry-matter basis. To balance and feed rations, it is important to be able to convert them back and forth. The following example demonstrates how to make the conversion using a TDN as an example:

$$\frac{\text{TDN value on air-dry basis}}{\text{Dry-matter content of feed}} \times 100 = \text{TDN on dry-matter basis}$$

For hay, TDN was calculated to be 50.4% on an air-dry, "as-is," or "as-fed" basis. The following steps convert it to a dry-matter basis:

$$\frac{50.4}{0.91 \text{ (moisture content was 9\%)}} \times 100 = 55.4\% \text{ TDN}$$

The step can be repeated for the other nutrients, as demonstrated for crude protein (CP):

$$\frac{13.0 \text{ (protein content on air-dry basis)}}{0.91 \text{ (Dry-matter content of feed)}} \times 100 = 14.3\% \text{ CP on dry-matter basis}$$

Measures of Energy

Energy is needed by different animals in very different amounts. Choosing the correct unit can help keep the math simple and the numbers easier to read. The units of energy measurement most frequently used are:

Calorie (cal) = Amount of heat or energy needed to raise 1 g of H_2O 1°C from 14.5° to 15.5°C

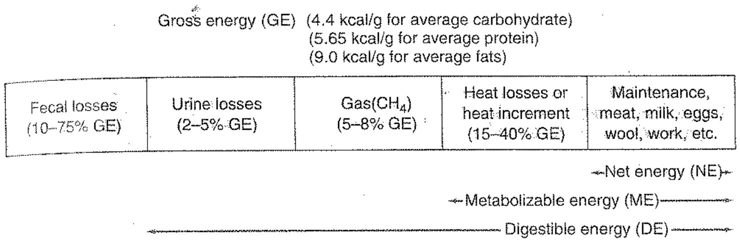
Kilocalorie (kcal) = Energy required to raise 1,000 g of water from 14.5° to 15.5°C = 1,000 calories

Megacalorie (Mcal) = 1,000 kcal or 1,000,000 calories.

In human nutrition, the term *kilocalorie* is used to measure and describe energy, although by convention we use the term *large calorie (symbol Cal),* which is equivalent to 1,000 small calories of about 4.2 kilojoules. For pet species, kcal is commonly used. In livestock nutrition, Mcal are most frequently used because of the large amount of energy these species need. The figures 80 Mcal and 80,000 kcal represent the same amount of energy. The smaller number is more convenient to use when performing the math associated with ration formulation.

Energy Content of Nutrients

Carbohydrates, proteins, and fats all provide energy to the animal. However, their energy contents (energy densities) are very different. Carbohydrates have approximately 4.0 kcal/g, whereas proteins have approximately 5.65 kcal/g on the average. However, about 1.65 kcal/g are lost as urea in the urine. The actual average gross energy value of most carbohydrates is about 4.4 kcal, but some energy is not digested, so we normally adjust the value to 4.0 kcal/g to compensate. The



Therefore, formulas for calculating the various energy values (DE, ME, and NE) of feeds are as follows:

GE – fecal loss = DE
DE – gas and urine = ME
ME – heat losses = NE

Figure 5–9 *Schematic diagram for partitioning energy values of feeds.* (Source: Adapted from Wagner, 1977. Used with permission.)

gross energy value for protein (5.65 kcal/g) is higher than for carbohydrates, but approximately 1.65 kcal/g is lost as urea in the urine when protein is used as an energy source, so the net value is about the same as for carbohydrates: 4.0 kcal/g. Therefore, carbohydrates and protein are given the same value in calculating TDN. Fats have approximately 9.0 kcal/g. Fat is given a value that is 2.25 times greater (9.00/4.00 = 2.25) than the values of the carbohydrate and protein because it does have a higher energy content per unit of measurement. This is the reason for the 2.25 correction factor for fat in a TDN calculation, and this is why TDN is considered an estimate of the digestible energy (DE) of a feed on a carbohydrate equivalent basis (Figure 5–9).

The amount of energy lost from feed in the various compartments represented in Figure 5–9 depends on several factors, including the kind of feed, its digestibility, and the animal. The numbers in parentheses in Figure 5–9 represent the range of the losses. Losses in the feces are generally the largest and most variable. Highly digestible feeds have minimal losses in the feces; poorly digested feeds have much higher losses. These losses occur during digestion and metabolism and include heat of fermentation of the microbial population in ruminants and horses. Heat losses are usually the second largest and most variable losses.

Efficiency of Energy Use

The purpose of all the energy conversions in the body of animals is to convert energy into something useful, such as maintenance of the animals, and products such as meat, milk, work, wool, and eggs. Heat losses are also useful in the overall scheme because they help the animal maintain body temperature. The better the feed, the greater the efficiency of net energy production from feeds. Metabolizable energy is used with different efficiency for various productive functions, some of which are more important in some species than in others. For this reason, we use different units of energy in ration formulation for different animal species. Figure 5–10 summarizes the varying efficiencies of energy utilization for the various productive functions of the body. This all relates back to TDN. The following formula is used to convert TDN to digestible energy and metabolizable energy:

1 lb TDN = 2.0 Mcal DE or 1.7 Mcal of ME

Figure 5–10
Efficiency of ME utilization.
(Source: Wagner, 1977. Used with permission.)

	Productive function	Efficiency
ME	Maintenance	~ 70%
	Milk	70%
	Growth	65–70%
	Fattening (beef cattle)	35–58%
	Fattening (simultaneously with milk production)	70%
	Work	70%

Metabolism trials are more advanced digestion trials and include measures of such things as urine and hair loss. One particular type of metabolism trial is a **balance trial.** The goal of a balance trial is to measure total intake and excretion so that retention in the animal's body can be calculated. Net retention of a nutrient within the body is positive balance and net loss is negative balance. Thus, a metabolism trial also provides information on nutrient use after absorption by the animal. Balance trials are usually conducted to study protein, energy, and minerals. Collections include feces, urine, expired air, milk, eggs, sloughed skin, shed hair, dropped feathers, sweat, and measurement of heat loss.

Nutrient Requirements

The outcome of all the chemical tests and all the animal trials has been the development of a set of nutrient requirements for the various species of animals commonly used in agriculture, research, and as companions. The National Research Council, a branch of the National Academy of Science, publishes these nutrient requirements and recommendations for feeding animals in various stages of production. The publications are updated and republished periodically. Included in these publications is general nutrition information and nutrient requirements of the various species as well as information on the feeding value of the commonly used feeds for the species.

Examples of the type of information found in these publications are given in Tables 5–1 and 5–2. The publications include, *Nutrient Requirements of Beef Cattle, Nutrient Requirements of Dogs and Cats, Nutrient Requirements of Fish, Nutrient Requirements of Dairy Cattle, Nutrient Requirements of Horses, Nutrient Requirements of Laboratory Animals, Nutrient Requirements of Mink and Foxes, Nutrient Requirements of Non-Human Primates, Nutrient Requirements of Poultry, Nutrient Requirements of Rabbits, Nutrient Requirements of Small Ruminants*, and *Nutrient Requirements of Swine*.

Ration Formulation

The amount of feed offered to an animal during a 24-hour period is called a ration. Providing the proper nutrients for a given animal to accomplish its specific production function is what we try to accomplish when we balance, mix, and subsequently feed a ration. If we accomplish this, we can say we are feeding a *balanced* ration. In addition to being balanced, a good ration must be palatable and free of damaging amounts of molds, diseases, and other quality-lowering factors. The ration should be economical and not have any negative effects on the general health and well-being of the animal or product quality. As an example, some substances in feeds and weeds give undesirable odors and flavors to the milk of dairy cows and off colors in eggs. Others cause undesirable carcass characteristics. Such feeds must be carefully managed if they are to be used at all. Tables 5–3, 5–4, 5–5, 5–6, 5–7, and 5–8 give examples of balanced rations for some classes of animals.

Balance trial A type of metabolism trial designed to determine the retention of a specific nutrient in the body.

Table 5–1
Selected Nutrient Content of Feeds Commonly Fed to Poultry and Swine on an As-Fed Basis

Feedstuff	(IFN)	DM (%)	CP (%)	Lysine (%)	Vitamin E (mg/kg)	Niacin (%)	Thiamine (%)	Ca (%)	Fat (%)	ME Swine (kcal/kg)	ME Poultry (kcal/kg)
Alfalfa meal	1-00-023	92	17.4	0.7	111.0	37.0	3.4	1.4	2.8	1,705	1,480
Bakery waste	4-00-466	92	9.8	0.3	41.0	26.0	2.9	0.1	11.7	3,600	3,630
Corn, gluten meal, 60%	5-28-242	90	61.2	1.0	23.4	60.0	0.3	—[1]	1.8	3,585	—
Molasses, beet	4-00-668	78	6.6	—	4.0	41.0	—	0.1	0.2	2,320	1,980
Oats, grain	4-03-309	89	11.8	0.4	14.9	14.0	6.0	0.08	4.7	2,735	2,543
Wheat, bran	4-05-190	87	15.5	0.6	14.3	197.0	8.4	0.13	4.0	2,268	1,270

Source: Various National Research Council publications. Information has been simplified and numbers rounded.
[1]A — indicates that a feed does not have a significant amount of that nutrient.

Table 5–2
DAILY NUTRIENT REQUIREMENTS OF HORSES

Animal	Weight (kg)	DE (Mcal)	Crude Protein (g)	Lysine (g)	Calcium (g)	Phosphorus (g)	Vitamin A (10^3 IU)
Mature horses							
Maintenance	600	18	650	27	24	17	18
Stallions (breeding)	600	26	950	40	36	22	27
Lactating mares							
Foaling to 3 months	600	33.7	1,711	60	67	43	36
Working horses							
Very heavy exercise	600	41.0	1, 200	52	48	35	27
Growing horses							
4 months	200	16.0	800	35	47	26	9

Source: Nutrient Requirements of Horses, 6th ed., 2007, pp. 300–301, National Research Council. Information has been simplified and numbers rounded.

Table 5–3
BALANCED CREEP DIETS FOR LAMBS

	Diet 1 (%)	Diet 2 (%)	Diet 3 (%)	Diet 4 (%)
Corn grain	48	48	29	24
Wheat			21	
Milo				24
Soybean meal	9			
Cottonseed meal		9	7	9
Molasses	4	4	4	3
Limestone	1	1	1	2
Alfalfa hay or pellets	38	38	38	38

Source: Courtesy of Dr. Jerry Fitch, Oklahoma State University. Used with permission.

Table 5–4
A TOTAL MIXED RATION (TMR) FOR LACTATING DAIRY COWS

	Per Cow Daily
Alfalfa hay	10.0 lbs
Corn silage	36.0 lbs
Shelled corn	21.1 lbs
Soybean meal	7.4 lbs
Dicalcium phosphate	3.8 oz
Limestone	5.2 oz
Sodium bicarbonate	7.1 oz
Trace mineralized salt	2.4 oz
Vitamin A	59,200 U
Vitamin D	29,600 U

Source: Adapted from Dunham and Call, 1989, p. 10.

Table 5–5
SUGGESTED MODERATE NUTRIENT DENSITY DIETS FOR GROWING SWINE USING SORGHUM GRAIN AND/OR BARLEY AS MAJOR GRAIN SOURCES[1]

Ingredient	Diet 1 (lb)	Diet 2 (lb)	Diet 3 (lb)	Diet 4 (lb)
Sorghum grain	1,514	1,375	1,444	—
Barley	—	—	—	1,532
Soybean meal, 44%	437	—	—	319
Soybean meal, 48%	—	—	424	—
Soybeans, full fat (cooked)	—	577	—	—
Fat	—	—	80	100
Calcium carbonate	17	17	18	18
Dicalcium phosphate	22	21	24	21
Salt	7	7	7	7
Trace mineral and vitamin mix	3	3	3	3
Totals	2,000	2,000	2,000	2,000

Source: Luce et al., 1995, p. 10.
[1]Suggested for average and high lean gain barrows 75–140 lbs, average gilts 75–140 lbs, and high lean gain gilts 140 lbs to market.

Table 5–6
EXAMPLE RATIONS FOR SOME COMPANION SPECIES (PERCENTAGE OF RATION)

	Dog	Cat	Rabbit	Guinea Pig	Hamster
Ground yellow corn	56.0	33.77	—	—	52.93
Ground wheat	5.0	9.0	36.5	23.6	13.47
Ground oats	—	—	—	25.25	7.54
Cornstarch	—	—	—	—	36.67
Molasses	—	—	3.0	—	0.70
Corn gluten meal (60% CP)	5.0	12.8	—	—	—
Soybean meal (48% CP)	15.0	10.0	6.0	12.0	22.0
Meat and bonemeal	10.0	3.0	—	—	—
Fish meal	—	1.0	—	—	4.85
Poultry meal	—	17.4	—	—	—
Cellulose	—	—	—	—	2.04
Alfalfa meal	—	—	54.0	35.0	20.0
Animal digest	—	1.0	—	—	—
Animal fat	7.0	6.0	—	—	—
Soybean oil	—	—	—	1.5	1.25
Vitamin/mineral premix	—	—	—	0.40	—
Vitamin premix[1]	0.8	0.8	—	—	0.08
Trace mineral premix[1]	0.5	0.5	—	—	0.05
Dicalcium phosphate	0.2	—	—	0.50	1.8
Ground limestone	—	—	—	—	0.5
Calcium carbonate	—	1.16	—	1.0	—
Salt	0.5	0.7	0.5	0.75	0.50
Potassium chloride	—	0.48	—	—	—
Phosphoric acid solution	—	2.3	—	—	—
Citric acid	—	0.01	—	—	—
Taurine	—	0.08	—	—	—
Brewer's yeast	—	—	—	—	6.46
Choline	—	—	—	—	0.14
DL-Methionine	—	—	—	—	0.05

Sources: *Nutrient Requirements of Laboratory Animals*, 4th ed., 1995, National Research Council; Pond et al., 2005, pp. 522, 527.
[1]The specific premixes are different for each species.

Table 5–7
RATIONS FOR BEEF CALVES (PERCENT OF RATION)

	Feed for Growing Cattle	Supplement for Grazing Steers
Cottonseed hulls	14.0	—
Cottonseed meal	—	86.0
Alfalfa pellets	19.0	—
Soybean meal	10.3	—
Salt	0.25	—
Calcium carbonate	0.6	—
Vitamin/mineral/additive premix	0.05	3.0
Dicalcium phosphate	0.6	—
Wheat middlings	—	7.0
Corn	51.0	—
Molasses	4.2	4.0

Source: Adapted from Lalman, 2008, pp. 156, 159.

Table 5–8
RATIONS FOR MATURE HORSES

	As-Fed Basis		Dry-Matter Basis	
All Feeds in the Ration	(lbs/day)	(%)	(lbs/day)	(%)
Bermuda grass, late	13.001	70.000	12.091	70.898
Oats, grain	3.715	20.000	3.313	19.429
Corn, dent, grain	1.393	7.500	1.226	7.188
Soybean meal 44% PRO	0.371	2.000	0.331	1.941
Sodium chloride	0.046	0.250	0.046	0.272
Calcium carbonate	0.046	0.250	0.046	0.272
Total ration	18.573	—	17.054	—

Source: Freeman, 2011.

SUMMARY AND CONCLUSION

Nutrition is a dynamic and very complicated science. It is essential that we understand nutrition because feeds and the methods of feeding comprise a large portion of the costs of livestock production. This chapter will not make you a world-famous nutritionist. However, it does give you a broad working knowledge on which to build. The key to understanding the interconnectedness of nutrition is in reducing it to its essentials:

1. Nutrition is the study of how the body uses nutrients for maintenance and production.
2. Nutrients are the chemical entities that the body requires. We need to know which nutrients and how much of each is required for the animal we are feeding.
3. Feeds contain nutrients. We must determine just how much of a particular nutrient is in each feed and then determine how much the animals can actually use.
4. When we know an animal's nutrient needs and a feed's nutrient availability for that animal, we can balance a ration from those ingredients to meet the animal's needs.

STUDY QUESTIONS

1. Define nutrition and explain why one might choose to study it.
2. Why is the proper feeding of livestock such an important practical consideration?
3. Describe the disciplines of nutrition including the areas of specialty for nutritionists. Explain the differences between basic and applied nutritionists.
4. Name and describe at least five disciplines involved in the study of nutrition.
5. Describe how you would set up an experiment to determine whether a nutrient is essential. How would you interpret the results?
6. List the nutrient categories. Why isn't energy a nutrient? Is it required for life?
7. List the essential amino acids. Are there any additional amino acids for poultry? Are there any deviations from this list?
8. List the fat-soluble vitamins.
9. List the water-soluble vitamins.
10. What is the difference between macro- and microminerals?
11. List all of the macrominerals and microminerals.
12. What are the overall body functions for which an animal uses nutrients?
13. What is the purpose of having feeds chemically analyzed?
14. What are the three general types of analytical methods used to evaluate feedstuffs? Briefly define each method.
15. What nutrients are measured by proximate analysis? What are the limitations of each individual test?
16. Describe in detail how carbohydrates are determined by proximate analysis. How is this process different from the way the other proximate constituents are determined?
17. What individual carbohydrate fractions are determined in each part of the proximate carbohydrate fractions?
18. What is the major problem with the proximate analysis?
19. Why was the Van Soest fiber determination method developed? What advantages does it offer over proximate analysis?
20. Why is there no standard test for determining the vitamin content of feeds?
21. Describe in detail the tests for determining the energy content of a feed. What are the units used to express energy content?
22. How do feeding trials help to generate feeding standards for animals?
23. List the factors that may have an effect on nutrient utilization.
24. What are the common types of feeding trials?
25. Describe how a feeding trial, a digestion trial, and a metabolism trial differ.
26. What is the difference between values for a feed expressed on an as-fed basis compared to a dry-matter basis?
27. Describe the differences in the energy content of an average carbohydrate compared to an average protein and an average fat.

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