World of Dairy Cattle Nutrition

HOLSTEIN FOUNDATION

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"Developing Dairy Leaders for Tomorrow"

“World of Dairy Cattle Nutrition”

will help you acquire a better understanding of a cow’s digestive system and the basic principles of formulating rations to support the productivity and health of your dairy herd.

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Introduction

Feeding dairy cattle the proper diet is essential for raising healthy, high producing dairy cattle. In this booklet, you will learn what makes the dairy cow's digestive system unique. You will also be introduced to concepts of formulating diets to maintain the health and productivity of your dairy cows. This workbook was written with a step-by-step format to help you develop a better understanding of the basics before studying more detailed information, and is divided into ten main sections:

- Digestive System
- Rumen Microorganisms
- Nutrients
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- Dry Matter Intake
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Digestive System

Understanding the digestive system of the cow is necessary to understand the nutritional requirements of a dairy animal. A cow is a ruminant animal, which means they have one stomach that contains four compartments. Figure 1 illustrates the entire digestive system with each compartment labeled. This section describes each organ and the role it plays in the digestive system.

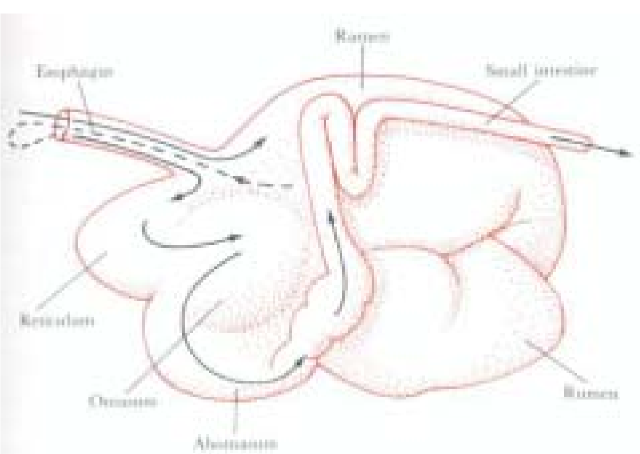


Figure 1. Parts of the Bovine Digestive System

Mouth

Ingested food passes through the mouth to the rest of the digestive system. While in the mouth, food is chewed and mixed with saliva. A mature cow can produce over 45 gallons of saliva per day. Saliva serves several functions, including moistening and lubricating food, allowing it to move down the throat more easily, and providing a fluid base for the digestion of nutrients and the proper environment for bacterial growth. Another important function of saliva is to act as a buffer, neutralizing the pH in the rumen. Without the buffers in saliva, the acids produced by rumen microorganisms would cause the rumen to be too acidic for proper rumen fermentation.

Several factors influence the quantity of saliva produced by an animal. Most of these factors involve physical stimulation, including stimulation of the mouth during eating, stretching of the esophagus during swallowing, and stimulation of the tongue during eating and rumination. Two other factors that increase salivation are **asphyxia**, the lack of oxygen occurring when an animal eats and reduces breathing, and increased gas pressure in the rumen.

Esophagus

When food leaves the mouth it travels down the esophagus by a muscular movement called **peristalsis**. Peristalsis is the contraction of muscles in the gastro-intestinal tract in a wave-like motion that pushes food along.

Rumen

The feed passes through the esophagus into the first compartment of the stomach, known as the rumen. This compartment is by far the largest stomach compartment, with a volume of 40 to 50 gallons in a typical cow. The rumen is also known as the "fermentation vat" because feedstuffs undergo a fermentation process while in the rumen. This process will be explained in more detail later.

The inside surface of the rumen is covered with papillae, small finger-like projections that aid in absorption by increasing the surface area of the rumen. The rumen contains 5 compartments that are partially separated by muscular tissues. They are known as the:

- Cranial sac
- Dorsal sac
- Ventral sac
- Caudodorsal blind sac
- Caudoventral blind sac

When feed is first swallowed it enters the cranial and dorsal sacs, while the liquids go to the ventral sac. The cranial sac is toward the front of the rumen, while the dorsal sac is toward the top of the rumen (or toward the cow's backbone). The ventral sac is located on the ventral or lower side of the rumen, and contains mostly liquid. Lighter and larger particles such as partially digested forages float to the top of the rumen (the dorsal sac) and form a floating mat of partially digested feed. The blind sacs (caudodorsal and caudoventral) do not lead anywhere, but hold partially digested feed to allow the microorganisms time to digest it.

The materials of the rumen are mixed through a series of muscular contractions which occur roughly once a minute in a healthy cow. The contractions mix the liquids with the solids which aids in digestion. When the rumen contracts, the liquids in the ventral sac are forced up through the rumen mat, ensuring good contact between the microorganisms and the feed they need to digest. Also, small grain particles can be caught in the rumen mat, allowing the microorganisms time to digest them before they pass from the rumen.

Rumination

If you have ever watched a ruminant animal eat, you have probably noticed that they do not chew their food well. Dairy cattle and other ruminants are unique because they can eat fast and chew later. The process of eating food and chewing it later is called **rumination** or chewing the cud. Rumination occurs when the animal is relaxed. Cattle spend 7-10 hours of the day ruminating. The majority of that time is spent ruminating forages. The steps of rumination include:

1. **Regurgitation** - when the feedstuff **bolus** or cud is regurgitated or brought back up. This is possible through **reverse peristalsis**. Just as peristalsis was the muscular movement that sent food down the esophagus, reverse peristalsis brings it back up.
2. **Remastication** - the process of chewing again.
3. Swallowing
4. **Eructation** - burping up gases produced in the rumen by the bacteria or microorganisms as they digest the food (mostly methane and carbon dioxide). Bloat results when an animal is unable to expel gas that has accumulated in the rumen.

Reticulum

The reticulum is the second compartment of the ruminant stomach. The rumen and reticulum are not completely separate from each other, and are often referred to as the reticulo-rumen. Another name for the reticulum is the "honeycomb" stomach because the inside surface has a honeycomb texture. The primary function of the reticulum is sorting of material based on size, to return large particles to the rumen for further digestion. Because swallowed material actually passes over the reticulum on its way to the rumen, heavy particles or foreign objects typically accumulate here. **Hardware Disease** will be discussed in a later section.

Omasum

After feed passes through the rumen and reticulum, it enters the omasum. The omasum is also called many plies because it is filled with many leaves (plies) that resemble pages in a book. These plies are very important in increasing the surface area for water absorption. The omasum absorbs approximately 60-70% of the water entering the omasum, or about 26 gallons of water per day.

Abomasum

The final compartment of the stomach is the abomasum, otherwise known as the true stomach. This compartment is most similar to the stomach of humans and other **monogastric** (single-stomached) animals. The abomasum secretes a gastric juice which contains hydrochloric acid (HCl), causing the abomasum to be very acidic, with a pH level of about 2.

The abomasum also secretes two **enzymes**: pepsin and rennin. An enzyme is a compound that helps speed up changes in other materials without being changed itself. **Pepsin** is important for digesting and breaking down proteins. **Rennin** is only secreted in young animals and helps to thicken the milk so it can be digested by the calf.

Esophageal Groove

The rumen and reticulum are not well developed in a newborn calf, so these are of little use in digesting and absorbing milk. Instead of flowing into the rumen milk is diverted from the esophagus to the omasum, the third stomach compartment, by a structure called the **esophageal groove**. The esophageal groove is a continuation of the esophagus that allows the milk to bypass the rumen and reticulum and go directly to the omasum where it can begin the digestion process. The esophageal groove is a muscular tissue that closes to form a tube when a calf begins a sucking action.

The development of the rumen and reticulum in calves is triggered by the consumption of hay and grain. As the calf eats more and more solid feed, the rumen wall gets thicker, the rumen gets larger, and papillae form. This development is triggered primarily by the volatile fatty acids produced by the fermentation of hay and grain, rather than by physical factors as was once thought. The production of volatile fatty acids will be discussed more in a later section.

Small Intestine

Partially digested feed, known as **digesta** or **chyme**, flows from the abomasum to the small intestine. The average small intestine is 130 feet long and holds 10 gallons of digesta. The inside surface of the small intestine is covered with **villi**, small finger-like projections which increase the surface area of the intestinal wall. The small intestine is the primary site of nutrient absorption in all animals.

The small intestine is made up of three different sections, the **duodenum**, the **jejunum**, and the **ileum**. The duodenum is the first section, and is where secretions from the pancreas and liver enter. The small intestine itself also secretes several enzymes, primarily in the duodenum. These secretions help break down starches and carbohydrates into simple sugars which are easily absorbed. Examples of these enzymes are amylase, an enzyme that digests starch; lipase, an enzyme that digests lipids or fats; and peptidase, an enzyme that digests proteins to amino acids. The suffix "ase" tells you that the compound is an enzyme.

Pancreas

The pancreas is a small gland located just below the abomasum. The juices secreted by this gland contain buffers, which help to neutralize the acidic stomach contents when they enter the small intestine. If there wasn't any way to increase the pH to near neutral, the acid secreted in the abomasum would burn through the lining of the small intestine.

In addition to secreting buffers, the pancreas secretes several types of enzymes and **hormones**. A hormone is a substance secreted into the blood that acts on tissues in other parts of the body to produce a biological response. Insulin and glucagon are examples of hormones secreted by the pancreas.

The enzymes secreted by the pancreas each have a specific duty. Some enzymes break down proteins into amino acids, others break up fats into fatty acids and glycerol and others convert starches into sugars. Each of these processes is important in digesting the food and making it available for absorption.

Liver

The liver secretes **bile** into the small intestine. Bile helps to neutralize the digesta as it enters the small intestine, and is important for the digestion of fats. Bile is stored in the gall bladder and is released into the intestine when needed. A high fat content in the digesta actually triggers the release of a hormone that causes release of bile. Bile also aids in breaking up fat into small particles which are easier to digest and absorb through the intestinal wall.

In addition to secreting bile, the liver plays a tremendously important role in converting certain absorbed nutrients into compounds that are more useful to the animal. One example of this is the conversion of propionate and lactate absorbed from the rumen into glucose. The cow needs glucose for the synthesis of milk, and for use by the brain and central nervous system, but she doesn't absorb anywhere near as much glucose as she needs. The liver synthesizes nearly all of the glucose needed by the cow every day. This process is known as **gluconeogenesis**. The liver also converts absorbed fatty acids into forms better suited for transport through blood and use by the tissues, and converts absorbed ammonia into the less toxic compound urea. The liver is truly the workhorse of the digestive system in all animals, and doesn't always get as much respect as it deserves!

Large Intestine

After digesta flows through the small intestine, where most of the nutrients are absorbed, it flows into the **large intestine**. The large intestine is made up of the **cecum** and **colon**. It is a sacculated organ. It contains sacs to accumulate and slow passage of the digesta, rather than being a simple tube. The large intestine does not have the surface structures found in the rumen (papillae) and small intestine (villi). The main function of the large intestine is water absorption and storage of waste materials which will eventually leave the body through the rectum as feces.

While not a primary site of digestion and absorption, the large intestine is home to a population of microorganisms. These microorganisms ferment any remaining available nutrients in the digesta, producing volatile fatty acids and microbial protein as the microorganisms in the rumen do. The next section will have details on rumen microorganisms. The volatile fatty acids produced here can be absorbed and used by the animal. The microbial protein produced in the large intestine cannot be absorbed, however, and is lost in the feces.

Rumen Microorganisms

The rumen is home to billions of tiny microorganisms. They live in an environment that is nearly neutral with an average pH of 6.5, and is **anaerobic**, which means there is no oxygen present. There are four basic groups of microorganisms in the rumen. They are:

- Bacteria
- Protozoa
- Fungi
- Bacteriophage (viruses)

Ruminal microorganisms help ruminants utilize feeds containing certain nutrients which monogastric animals can't digest. Two examples are **cellulose** and **hemicellulose**, fibrous compounds found in plants. The structure of cellulose and hemicellulose makes them impossible to digest without the help of special enzymes (**cellulase** and hemicellulase). These enzymes are only secreted by microorganisms, allowing ruminants, but not monogastric animals, to digest fibrous plant materials.

There are many advantages to having microorganisms living in the rumen. The first is obvious; the microorganisms will digest cellulose and hemicellulose allowing the ruminant to extract energy and protein from feeds otherwise indigestible. These compounds and others in the diet are fermented by the microorganisms to **volatile fatty acids** (VFA). The VFA (primarily acetate, propionate, and butyrate) can be absorbed by the animal and are used by the tissues as sources of energy.

A second advantage to having microorganisms living in the rumen is that they can convert inexpensive non-protein nitrogen sources in the diet into protein for the animal's use. Most of the protein used by a ruminant is actually made in the rumen by microorganisms and is called **microbial protein**. Microorganisms can also make their own B vitamins, making supplementation of the diet with these vitamins unnecessary for ruminants. Finally, microorganisms can break down many toxins, making it less likely the animal will be affected by poisonous plants.

On the other hand, microorganisms also cause some disadvantages to the ruminant animal. Most of the food eaten by the ruminant gets digested by the microorganisms before it can be absorbed by the animal. Sometimes the microorganisms will decrease the quality of the feed before the animal uses it. This is most often true of feed proteins, and will be discussed in more detail in the section on protein.

Nutrients

Nutrients are substances that provide nourishment to the body. There are seven classes of nutrients essential to every living animal for survival. They are:

- Water
- Energy
- Protein
- Carbohydrates
- Fats
- Vitamins
- Minerals

Water

Water is the most important nutrient for dairy cattle, as a lack of water will cause death more quickly than a lack of any other nutrient. From 56 to 81% of the cow's body is made up of water, and maintaining body water is absolutely essential to life. In the body, water acts as a solvent, transports nutrients and waste materials, participates in many chemical reactions, and is important in body temperature control.

Every reaction or process that takes place in the body occurs in water. Water is also important in the transportation of substances throughout the body. Nutrients are transported through the digestive tract, through the blood stream, and into and out of cells in water-based solutions (i.e., digesta, blood, lymph). Water helps in the elimination of waste materials, through urine, feces, and respiration. Water also plays a role in many chemical reactions where a water molecule (H_2O) is added or taken away.

Another key function of water is its use in controlling body temperature. Sweating and panting result in the loss of water, and are the most effective ways for a cow to cool off. Animals and humans must drink more water during periods of heat because of this. Other functions of water include acting as a cushion for joints, aiding in lubrication, vision, and hearing.

Water is available to the body through three sources. The most obvious is drinking water, as most animals drink 2-3 times more water than the amount of feed they eat. Water intake increases during hot periods and with increasing milk yield. Another source of water is the moisture found in feedstuffs. Most feeds that we consider "dry" (grain, hay) contain 10-15% water. Silage is obviously much wetter, with a water content of 45-75%. The third source, accounting for 5-10% of water found in an animal's body, comes directly from chemical reactions which occur in the body. When two molecules of ammonia are combined in the liver to form urea, for instance, one molecule of water is released.

Energy

After water, energy is the primary nutritional need. An energy deficiency is the number one cause of reduced milk production, although it generally goes unnoticed. Animals need energy to produce milk, to grow, to maintain their 1400+ pound frame, and to support pregnancy. Measuring the energy content of feed or the energy needs of the cow is somewhat difficult, and the units used can be unfamiliar. Figure 2 outlines the traditional energy partitioning scheme.

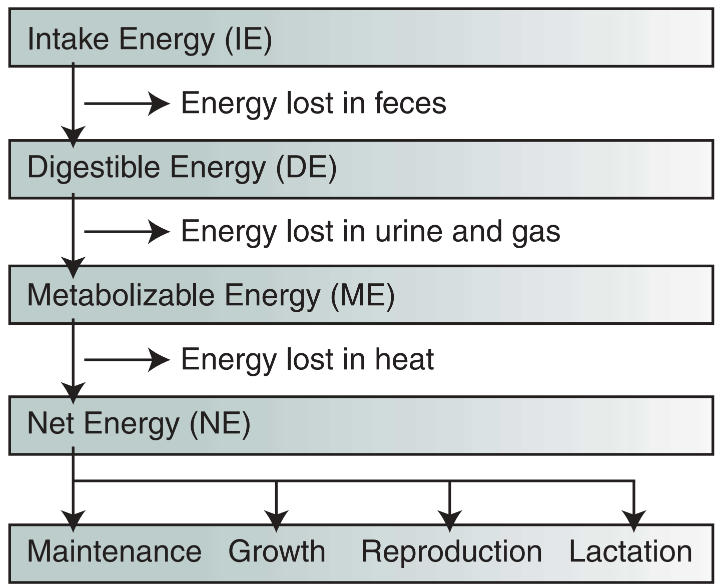


Figure 2. Traditional Energy Partitioning Scheme

Intake Energy

This schematic outlines the partitioning of energy consumed by the animal. The **gross energy** (sometimes called intake energy) of feed is the amount of energy that is in the feedstuff and is ingested by the animal. It is measured with a bomb calorimeter, a device that literally burns the feed, and measures the heat released in units of calories, kilocalories (kcal; 1000 calories), or megacalories (Mcal; 1000 kcals). The heat released when a feed is burned is used as a measure of the total energy contained in the feed. The calorie content listed on the nutrient label of foods you eat was measured this way.

Unfortunately, not all of the total energy contained in the feed (intake energy) is available to the cow for her to use for growth, milk yield, pregnancy, etc. Some of the intake energy of a feed is indigestible, and some will be wasted by the body after absorption. We need a way to accurately quantify these losses in order to account for the difference in the ability of different feeds to support production.

Digestible Energy

The first loss to be accounted for is the energy lost in feces. Energy is lost in feces when the animal does not digest all of the energy she consumes. Many forages are less digestible than grains, meaning that more of their energy is lost in feces. Intake energy minus the energy lost in feces is known as **Digestible Energy** (DE). The DE content of feeds is reported in feed composition tables. These values were calculated from hundreds of research studies in which feces production and fecal energy content was measured in cows fed various feeds. Again, the calorie (kcal or Mcal) is used as a measure of the DE content of a feed.

Metabolizable Energy

Even measuring DE, which accounts for the energy lost in the feces, doesn't accurately measure the useable energy in a feed, however. Some digestible energy is lost as urinary energy, and some is lost in the production of gasses such as methane. The energy remaining after these losses is known as **Metabolizable Energy** (ME). Gaseous energy losses can be quite high in a ruminant, and again, are usually higher in forages than in grains. Metabolizable energy is the energy available to the tissues (muscle, fat, mammary gland, etc.) to support chemical reactions, and is expressed in calories (kcal or Mcal).

Net Energy

Finally, even after the energy from a feed arrives at the tissue, there are still energy losses to account for. As chemical reactions take place in the body, some energy is lost as heat. The ME content of a feed minus the heat lost during metabolism is known as the **Net Energy** (NE; sometimes referred to as **Retained Energy** or RE) content of the feed. Net energy is the total amount of energy that an animal can use for maintenance of the body, growth, pregnancy, and lactation.

Dilution of Maintenance

The **maintenance requirement** of a cow is the energy required just to maintain the cow's body, and it remains basically constant for mature animals. The NE content of the feed reflects the total useable energy, but the cow's maintenance requirements must be met before any production (growth, milk, pregnancy) can occur.

Because maintenance requirements are the same regardless of feed intake, and because these requirements are met first, every additional unit of NE consumed above the maintenance requirements increases the amount of energy available for production. When energy intake increases above maintenance, the added energy goes toward increasing production. This is why increasing feed intake almost always improves productivity. Figure 3 outlines this relationship between NE intake and energy available for production.

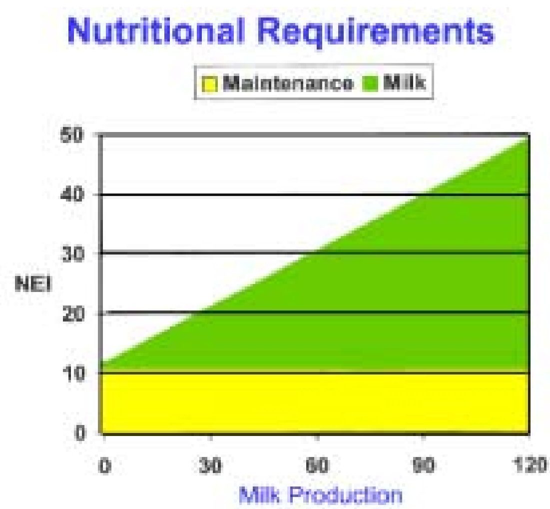


Figure 3. Dilution of Maintenance Cost with Increasing Energy Intake

High Energy Feeds

Energy is available from three dietary sources: fats, proteins and carbohydrates. Fats have the highest energy value per pound of feed, with protein and carbohydrates next. Common feed ingredients used to increase the energy density of the diet include forages, cereal grains, fat supplements and by-product feeds. Examples of high energy forages include corn silage or small grain silage. High energy cereal grains include corn, barley and sorghum. By-product feeds including beet pulp, citrus pulp, and bakery waste are used as sources of energy in some situations.

Protein

Protein is made up of **amino acids**, which are known as the building blocks of proteins. Amino acids contain carbon (C), hydrogen (H), oxygen (O), and nitrogen (N), and some contain sulfur (S). There are 22 known amino acids found in nature. Different combinations of these amino acids make up the various types of protein.

Proteins have many different functions in the body. They are important structural components of many tissues, and can be found in muscle, skin, feathers, hair, bone, fingernails, muscle tissues, and blood. Several hormones are proteins, including insulin and bovine somatotropin. The enzymes important in digestion, absorption, and metabolism are all proteins.

Amino acids bonded together form proteins. Enzymes secreted by the abomasum, pancreas and small intestine break these bonds to separate the amino acids and allow them to be absorbed by the body. It is important to note that proteins must be broken down to amino acids before absorption, so it is technically incorrect to refer to absorption of proteins. Proteins are not absorbed; amino acids are.

Amino acids can be divided into two groups, essential and non-essential. Essential amino acids are those which are not produced by the body and therefore must be provided in the diet. Nonessential amino acids are produced by cells and are not needed in the diet. The essential amino acids are listed below, and can be remembered by the acronym made up by the first letter in each, PHILL MT VAT.

- Phenylalanine
- Histidine
- Isoleucine
- Leucine
- Lysine
- Methionine
- Tryptophan
- Valine
- Arginine
- Threonine

Protein Digestion in the Rumen

In humans and other monogastric animals, the amino acids contained in the proteins in food will arrive in the small intestine relatively unchanged. This makes it fairly straightforward to predict which amino acids will be available for absorption in what quantities. Unfortunately, this is not the case in ruminant animals, because the ruminal microorganisms alter the proteins dramatically before they reach the small intestine for absorption.

The protein in feeds may be digested in the rumen, or may escape rumen fermentation. The portion of feed protein that is digested in the rumen is known as **ruminally degraded protein** (RDP). This protein fraction is also sometimes known as degradable intake protein (DIP). The ruminal microorganisms digest RDP, breaking it down to amino acids, and then to ammonia. The microorganisms then take up these amino acids and/or ammonia, and form new amino acids and new proteins, known as **microbial protein**.

Ruminal microorganisms have short life spans, of several hours at most. When the microorganisms die, and pass from the rumen, their bodies are digested in the abomasum and small intestine. The microbial protein contained in the bodies of the microorganisms is digested to amino acids in the small intestine, and these amino acids are absorbed. Microbial protein (NOT feed protein) actually provides the majority of the protein digested and absorbed by the animal.

The fraction of the protein in feed that escapes rumen fermentation is known as **ruminally undegraded protein** (RUP). This fraction is also sometimes known as undegradable intake protein (UIP) or as bypass protein. The RUP fraction of the feed passes from the rumen unchanged, and may be digested in the abomasum and small intestine, and the resulting amino acids absorbed. Some RUP is completely indigestible, and passes from the body in feces.

Although some feeds are commonly referred to as sources of RDP or as sources of RUP, it is important to remember that nearly all feeds contain some of each of these two protein fractions. Feeds whose proteins are largely digested in the rumen (and so are good sources of RDP) include urea, soybean meal, and alfalfa hay or silage. Feeds like distillers grains, brewers grains, roasted soybeans, blood meal, and fish meal are good sources of RUP.

The First Limiting Amino Acid Concept

The quantity and balance of amino acids in proteins reaching the small intestine to be digested (either in microbial protein or in RUP) are important in determining the animal's productivity. The animal fits together the amino acids absorbed from the small intestine to synthesize the proteins needed for growth, maintenance, milk production, or pregnancy. Each protein synthesized requires a specific combination of amino acids, and if an essential amino acid is in short supply, it can not be replaced by another. The amino acid supplied in the smallest amount relative to the amount required for protein synthesis is known as the first limiting amino acid, because it limits the amount and type of protein that can be made.

If the animal needs to synthesize a small protein made up of 4 arginines, 5 threonines, and 3 lysines, for instance, a shortage of any of these will prevent the synthesis of that protein. If the cow has absorbed 8 arginines, 12 threonines, and 5 lysines, for instance, she can make one, but not two, copies of this protein. While she has enough arginine to make 2 copies (8 available, 4 needed per protein) and more than enough threonine for two copies (12 available, 5 needed per protein, she has only enough lysine for one copy (5 available, 3 needed per copy). Lysine is the first limiting amino acid in this example. Not only can she only make one copy of the protein, the lack of lysine means that the extra arginine and threonine are wasted. Excess amino acids which are not used because the limiting amino acid prevents protein synthesis are removed from the body in the urine.

Another example closer to most of our hearts may more clearly explain this important concept. Say you are making strawberry pies, for a bake sale or maybe just because you have the urge to eat strawberry pies. Each pie requires 1 cup of flour, 1 cup of shortening, and 4 cups of strawberries. You have 5 cups of flour and 6 cups of shortening, but only 16 cups of strawberries. You have enough flour and shortening to make 5 pies, but will run out of strawberries after making 4 pies. Strawberries are the first limiting ingredient, and the extra cup of shortening will be wasted.

In dairy rations, lysine and methionine are the most common limiting amino acids, because common feeds (corn, corn silage, soybean meal) are relatively low in these amino acids compared to the quantities needed for milk synthesis. Fish meal and blood meal are good sources of lysine, while corn gluten meal, fish meal, and sunflower meal are good sources of methionine. Designing rations using small amounts of these protein supplements in addition to standard ingredients may increase milk protein yield and reduce nitrogen excretion in urine. Ruminant protein nutrition is complex, however, and positive responses to inclusion of these ingredients are not consistently observed.

Carbohydrates

Carbohydrates are nutrients made up of carbon (C), hydrogen (H) and oxygen (O), and are the main energy storage compound in plants. Plant tissues are high in carbohydrates such as starch, cellulose, and hemicellulose. The basic building blocks of carbohydrates are the **monosaccharides** or "simple sugars". A monosaccharide with six carbon molecules is known as a hexose ("hex" meaning six). The most common of these is glucose, but galactose, mannose, and fructose are three other common hexoses. Another common monosaccharide has five carbons and is called pentose ("pent" meaning five). Ribose is a common pentose monosaccharide.

When two monosaccharides are joined together they form a **disaccharide**. Lactose (milk sugar) and sucrose (table sugar) are two common disaccharides. As the prefix "di" means two, the prefix "poly" in **polysaccharides** means many monosaccharides. Starch, cellulose, and hemicellulose are the most common polysaccharides.

When ruminants eat carbohydrates, the ruminal microorganisms release enzymes that break them down into monosaccharides. The monosaccharides are then converted by the microorganisms into VFA. Volatile fatty acids are absorbed across the wall of the rumen and the small intestine, and are used by an animal as an energy source. Again, the three most important VFA are acetate, propionate, and butyrate.

Carbohydrates in feedstuffs are commonly divided into two categories: fiber, and non-fiber carbohydrates (NFC). The fibrous carbohydrates are cellulose and hemicellulose. These are found in the cell walls of plants, and are indigestible to monogastrics. As discussed earlier, though, microorganisms contain enzymes to digest these fibrous carbohydrates. The common non-fiber carbohydrates include starch, pectins, and sugars.

Fibrous carbohydrates in a feed are measured by the neutral detergent fiber (NDF) assay and the acid detergent fiber (ADF) assay. Neutral detergent fiber contains all of the cell wall carbohydrates, cellulose, hemicellulose, and lignin. Lignin is indigestible even by the ruminal microorganisms. The NDF content of the feed closely reflects its bulk, and is often used to predict how much a cow will be able to eat of a diet without exceeding the capacity of her digestive tract. Acid detergent fiber contains cellulose and lignin, and is closely associated with the digestibility of a feed. The ADF content of a feed is commonly used to predict the energy value of that feed, because of this association with digestibility.

Non-fibrous carbohydrates (starch, pectins, sugars) are not as easy to measure directly as ADF and NDF are. Few commercial labs analyze samples for these compounds because the assays are difficult. Instead, the non-fiber carbohydrate (NFC) content of a feed is usually estimated by adding up its protein, NDF, mineral, and fat content, and subtracting these from 100, assuming that everything else is NFC. This is a fairly crude estimate, but is often the best one available.

Fats/Lipids

Another nutrient essential to an animal's diet is fat, also known as lipid. Fats are found in many common feedstuffs, and fat supplements are often added to diets to increase its energy density. Fat supplements may also improve the absorption of fat soluble vitamins, and help to reduce dustiness of feed. Fat is a very important part of a young ruminant's diet because calves require tremendous amounts of energy. Fat commonly makes up 10-25% of their diet.

There are a variety of sources of fats in ruminant diets. Oilseeds like whole cottonseed or whole soybeans contain large amounts of fat, and are often fed as energy supplements. Also, relatively pure fat supplements made up of animal fat (i.e., tallow) or blends of animal and vegetable fats (white or yellow grease) may be fed. While adding fat to the diet increases its energy content, fat supplements can have negative effects on rumen fermentation and dry matter intake. To reduce these negative effects, some fat supplements are specially formulated to be ruminally inert, or to have minimal effects on rumen fermentation.

Fats from plant and animal sources are classified as either saturated or unsaturated. In a saturated fat, each of the carbon atoms in the **fatty acids** is bonded to hydrogen atoms and to its neighboring carbon atom with a single bond. The fatty acid is said to be "saturated" because it contains the maximum possible number of hydrogen atoms. In unsaturated fats, one or more pairs of carbon atoms in the fatty acids are joined by a double bond. It is unsaturated because at least one pair of carbon atoms does not contain the maximum possible number of hydrogen atoms. During rumen fermentation, most of the unsaturated fats in the diet are converted to saturated fats. This is why most of the fat in the milk and meat of ruminants is saturated fat.

Vitamins

Although only small amounts of vitamins are required by the cow, deficiencies of these nutrients can cause major problems. Vitamins can be broken down into two categories: water soluble vitamins and fat soluble vitamins.

Water soluble vitamins are not stored in the body tissue and therefore must be provided in the diet of young ruminants and non-ruminants every day. In healthy adult ruminants, the rumen microorganisms synthesize enough of these vitamins to meet the animal's requirements. Water soluble vitamins include thiamin (vitamin B_1), riboflavin (B_2), pyridoxine (B_6), cobalamin (B_{12}), nicotinic acid (niacin), pantothenic acid, biotin, folic acid, choline, and ascorbic acid (vitamin C). The functions of these vitamins, and signs of their deficiency are listed in Appendix Table 1.

In addition to these water soluble vitamins, there are four fat soluble vitamins. These vitamins can be stored by the animal in large quantities for several months. This makes day to day variation in their intake less of a problem, but makes toxicity more likely if dietary levels are too high. The fat soluble vitamins include vitamins A, D, E, and K. The functions of these vitamins, and signs of deficiency or toxicity are listed in Appendix Table 2.

Vitamins A, D, and E are commonly supplemented in lactating cow diets. They are especially needed when forages have been stored for long periods of time, in young animals fed milk replacers or calf starters without hay, when raising veal calves, when forage has been rained on, in periods of stress, and when animals are housed indoors. If milk has an oxidized off-flavor, vitamin E supplementation may help, and supplementation of vitamin E in combination with the mineral selenium may boost the cow's immune system, reducing the incidence of mastitis.

One practical aspect of feeding vitamins that needs special consideration is their storage. Vitamins A and E are particularly susceptible to degradation over time, especially when exposed to sunlight or air. To avoid this degradation, storage of mineral supplements for long periods of time before feeding is not recommended.

Minerals

Minerals required by the animal in gram quantities are known as **macrominerals**. These include calcium (Ca), phosphorus (P), sodium (Na), chlorine (Cl), potassium (K), magnesium (Mg) and sulfur (S). These minerals are used by the animal as components of bone and other tissues (Ca, P), to maintain acid/base balance (K, Na, Cl), to maintain osmotic pressure (Na) and membrane electric potential (K, Na, Cl), and for nerve transmission (Ca).

Microminerals are those required by the animal in milligram or microgram quantities. These include cobalt (Co), copper (Cu), iodine (I), iron (Fe), manganese (Mn), selenium (Se) and zinc (Zn). These minerals serve as part of metalloenzymes (Mn, Zn), or as enzyme cofactors (Co), or may be part of endocrine hormones (I).

The functions of the macro and micro minerals, and signs of their deficiency or toxicity are listed in Appendix Tables 3 and 4. Overfeeding of several minerals can cause toxicity or management problems. Special attention should be paid to avoiding overfeeding of copper, potassium, and phosphorus. Copper is the mineral most likely to cause toxicity, and Jerseys are particularly likely to suffer from this. Overfeeding potassium does not lead to toxicity, but does cause management problems. Overfeeding potassium increases potassium excretion, and land-application of manure from those cows will increase the potassium content of the crops grown. High potassium forages increase the risk of milk fever.

Overfeeding phosphorus also causes management problems for the farmer. Overfeeding phosphorus is of no benefit to the animal, and is of real environmental concern. Most farmers overfeed phosphorus by 40-50%, and every extra gram of this phosphorus above the animal's requirement comes right out the other end in feces. This increases the phosphorus content of manure, increasing the risk of phosphorus runoff from the farm and contamination of surface water. Most significant to the farmer, overfeeding phosphorus makes it much more difficult for him or her to land-apply manure under phosphorus-based nutrient management regulations. Rations that include soybean meal, distillers grains, cottonseed or other by-product feeds often require no supplemental phosphorus at all to meet the cow's needs.

Dry Matter Intake

The quantity of feed consumed by the cow is enormously important because it establishes the amount of nutrients available to maintain health and productivity. Dry matter intake (DMI) is calculated as the quantity of feed consumed times its dry matter content. The **dry matter** content of the feed is the proportion of feed that is not water. While feeds vary in their water content, all of the nutrients in feed are located in the dry matter portion. For this reason DMI gives a more accurate measure of nutrient intake than total feed intake (which includes the water in the weight of the feed consumed). Understanding the factors that affect DMI helps us maximize nutrient intake and productivity.

Accurate estimation of DMI is important in the formulation of rations. A cow requires all of the nutrients outlined above in specific quantities (i.e., pounds of protein or grams of phosphorus per day). The concentration of each nutrient needed in the diet, therefore, depends on both the requirement and the total amount of feed consumed by the cow in a day.

There are dozens of theories on what controls DMI in lactating cows. Most theories are based on one of two basic concepts, that gut fill limits intake, or that satiety limits intake. There is scientific evidence supporting each of these two competing concepts, and it is likely that which concept is "true" depends on the situation. In fact, the DMI of a cow at a given point in time is probably affected by some combination of these factors.

The first of these two basic concepts is that gut fill limits intake. According to this theory, cows will eat until they literally run out of room in their rumen or gastro-intestinal tract. The end of the meal is triggered by the stretching of the gut, and the cow cannot eat more until some of the feed she consumed is removed from her gut. This removal of consumed feed is by digestion or by passage of feed down the tract and out into the feces.

To test this theory, some researchers have added indigestible, bulky material to the diet (i.e. shredded plastic, or balloons). If the bulk fill theory is "correct", adding this material would decrease feed intake, because the plastic or balloons occupy space in the rumen, limiting the amount of feed the cow could consume. The evidence supporting this theory is strongest in early lactation cows, and in lower quality (less digestible) diets.

The second basic concept of feed regulation is that feed intake is related to satiety. **Satiety** is the state of being fully satisfied or having your metabolic needs completely met. According to this concept, the animal eats until its requirements (usually for energy) are met. Once these requirements have been met, feedback from some compound in the bloodstream signals to the cow that she should stop eating. There is much debate over what specific circulating compound triggers the end of a meal in cows. Some research indicates that VFA in the blood above a certain level causes the end of a meal, while other research suggests that it might be certain hormones or other compounds that the body releases in response to absorption of nutrients.

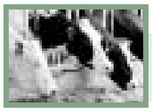
These satiety theories suggest that as energy density of a diet increases, the cow will eat less. It assumes that the cow eats only as much energy as she needs, and so daily energy intake is constant. This is only observed in cows fed highly digestible diets or in later lactation cows.

Again, there is evidence for both the gut fill theory of intake regulation and the satiety theory, and both are likely important at different stages of a cows productive cycle.

In addition to these two basic theories of feed intake regulation, there are other situations in which we can predict intake may be reduced. On very low protein diets, for instance, feed intake often declines. This may be because the diet does not contain enough nitrogen to meet the requirements of the microbes. Therefore the microbes aren't able to digest the diet well. Undigested feed then accumulates in the rumen, limiting feed intake through gut fill limitations.

Also, both scientists and farmers have observed that intake of silage is often lower than intake of similar hays. This was long thought to be due to the acidity of silage, but more recently, scientists have concluded that other side effects of silage fermentation are responsible for this reduced intake. Certain nitrogen-containing compounds in silage juices may impair DMI, or it may occur because silage fermentation makes silages lower in fermentable carbohydrates than hay. This reduced fermentable carbohydrate level in the feed might then impair the growth and efficiency of the rumen microorganisms.

Finally, close-up dry cows and early lactation cows both often have lower dry matter intakes than other cows of similar size. Close-up dry cows usually eat less as they get closer to calving. This may be due to the effect of fluctuating hormone levels, but more research needs to be done to clarify this. Early lactation cows usually have reduced feed intake compared to later lactation cows. This reduced intake probably occurs because the rumen shrinks during the dry period, and the cow simply can't fit enough feed in her gut to meet her needs just after she calves. The rumen expands over time after calving, and peak feed intake usually occurs by 10-14 weeks into lactation. This will be discussed in more detail in the next section.



Group Feeding

Modern dairy cows are expected to produce tremendous amounts of milk to meet the demands of the world's growing population. High milk yield is only possible when good management is matched with good genetics. Formulating a ration to meet the needs of the cows in the herd depends on knowledge of many factors including body size, stage of lactation, level of production, and stage of gestation. This process is made more complicated when the cow's appetite or capacity for feed intake is below the level which is needed to maintain her body, produce milk, and grow. The challenge facing dairy farmers is to meet the nutritional needs of their cows while minimizing weight loss or gain, preventing digestive problems, maintaining good health and supporting high milk yield. Figure 4 shows the relationship between milk yield, feed intake, and body weight throughout a lactation.

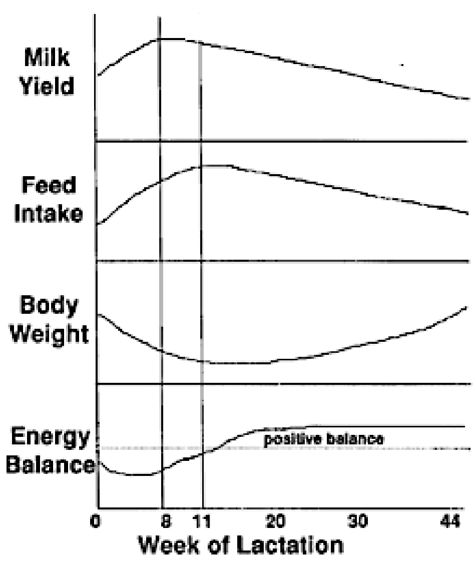


Figure 4. Relationship Between Milk Yield, DMI, and Body Weight Throughout Lactation

Milk production increases rapidly and reaches a peak at 4-8 weeks after calving. Notice, however, that the feed intake during that period has not yet peaked, and energy intake is usually less than energy requirements. In this stage, cows are said to be in negative energy balance, meaning that the cow must use her stored body nutrients to meet her production requirements. Cows in this stage of lactation typically lose weight and body condition. If a cow calves without sufficient body reserves (body condition) to make up for this negative energy balance, milk production will often suffer. On the other hand, care also needs to be taken to ensure a cow does not get overweight before she calves. Cows that are too fat at calving are more susceptible to a variety of metabolic disorders. These are discussed later in the workbook.

As lactation proceeds, feed intake increases to a peak at about 10-14 weeks. When energy intake exceeds energy needed for milk yield, the cow will begin to regain weight and replenish the body reserves she used in early lactation. Ideally, during late lactation and through the dry period, a cow's weight gain should be caused primarily by the growth of the unborn calf, rather than from putting on extra fat. If a cow is too thin when she is dried off, she should be fed accordingly to replenish her body reserves as well as to support fetal growth.

The ideal feeding program would allow you to feed each cow individually according to their specific needs. This is nearly impossible because of the difficulty in monitoring day to day changes in nutrient requirements for each cow. It is also impractical from a labor and cost perspective. Instead, many farmers group feed cows according to their stage of lactation and level of production. While grouping strategies vary depending on herd size and the available facilities, three groups of lactating cows and two groups of dry cows is one common strategy.

Group One: Early Lactation Cows

The first group in this strategy is for early lactation cows, before peak lactation. These cows are typically in negative energy balance, and are using body stores of nutrients. This period from calving to peak lactation is the most critical stage of lactation for a dairy cow. Every additional pound of peak milk production will result in about a 100 pound increase in milk production over the entire lactation. Therefore, the management and nutrition of dairy cows during this period have a very significant effect on milk yield throughout the entire lactation.

The primary goal in feeding early lactation cows is to increase the feed intake as rapidly as possible so the cow can minimize the nutritional deficiency. However, care must be taken to be sure the ration is not changed too rapidly, as this will cause digestive problems. Success in group one feeding will maximize peak production, minimize loss of body condition, minimize incidence of metabolic disorders, and return cows to a positive energy balance by 10-12 weeks after calving.

In early lactation, dairy cows are able to obtain needed energy from stored body fat, but protein is not as easily acquired from body store. Diets for these cows are typically higher in energy and protein than are diets for other groups, as feed intake is limited. Energy density may be increased by adding fat to the diet or by increasing the grain content. Both approaches have positives and negatives. Adding fat will increase the energy density without causing acidosis and milk fat depression. On the other hand, not all fat sources are palatable, and adding too much fat to the diet can impair rumen fermentation and fiber digestion.

Increasing the grain content of the diet is another way to increase energy intake. Increased grain feeding provides more energy for milk synthesis, and may increase milk protein synthesis as well. Additional grain is often less expensive than adding fat supplements. Designing diets is a balancing act, though, as increasing the grain content of the diet to increase energy intake may increase the risk of both acidosis and displaced abomasum. There is discussion of this in the grain and feeding section.

If a **total mixed ration** (TMR) is fed, the concentrate to forage ratio may be increased to a maximum of 60:40 (60% concentrate and 40% forage). A TMR is a diet where all the feedstuffs are mixed together before feeding. This provides the cow with a "complete meal in every bite", and reduces the cow's ability to selectively eat only the feeds she likes. If a TMR is not used, grain intake should increase slowly, and grain should be fed in at least 3 meals per day.

Because feeding early lactation cows is such a balancing act, and is so important to lactational performance, feed additives are often used in diets for this group. Adding buffers such as sodium bicarbonate or magnesium oxide may be beneficial to cows being fed high concentrate diets or diets high in corn silage. Propylene glycol drenches are sometimes used in these cows as they may reduce incidence of ketosis.

Also, many farmers include a small amount of long or chopped hay in diets for these early lactation cows to enhance palatability and maintain healthy rumen function. Some research indicates that including long stem hay in the diet or increasing forage particle size will decrease the incidence of displaced abomasum.

Group Two: Mid-lactation Cows

In this example grouping strategy, group two is for cows in mid-lactation, between about 10 and 20 weeks after calving. This is the stage of lactation when the nutrients consumed by the cow pretty well match the requirements for her level of production. An important goal in feeding this group of cows is to reach maximum feed intake and positive energy balance as early as possible, to help the cow maintain high production. Also, most cows will be bred while in this group, and being in positive energy balance improves conception rates.

In this stage of lactation, DMI will reach 3-4% of body weight for most cows. This will vary depending on the specific cow and production level. Feed intake is generally greater in higher producing cows. Some cows have the ability to consume up to 5% of their body weight (i.e. 75 pounds of feed on a dry matter basis for a cow weighing 1500 pounds).

Dietary protein and energy concentrations may be slightly lower during this stage of lactation than in early lactation because feed intake is higher. Even though cows are less likely to have digestive problems during mid lactation than in early lactation, care should still be taken to provide adequate fiber intake and particle size. The cost-effectiveness of feed additives for this group must be carefully analyzed, as these cows are not as prone to metabolic disorders as are early lactation cows.

Group Three: Late Lactation Cows

In this example grouping strategy, cows move to group three when they are pregnant, when milk yield drops, and significant weight gain is occurring. This stage is the best time to restore the cow's body reserves for the next lactation. The length of time that a cow stays in each stage will vary depending on the individual cow and the facilities available.

Of all of the groups, late lactation cows may be the easiest group to manage, because nutrient intake usually exceeds requirements, milk production is declining, and the cow should be pregnant. Group three is the time in which the cow should be replacing the weight she lost during high production in early lactation. The primary goal of this stage is to get the cow in appropriate body condition before drying off, and to maintain milk production as much and as cost-effectively as possible. Grain feeding is generally lower in this stage of lactation than in others, and fewer feed additives are used, often making these cows the least expensive to feed.

Group Four: Early Dry Cows

In our example grouping strategy, groups four and five are for dry cows. Cows move to group four following dry off, for any final addition to body condition and for regeneration of mammary tissue. Cows need a 45-60 day dry period to rest and prepare for the next lactation. Dry periods shorter than 40 days do not allow enough time for the mammary tissue to regenerate. The result is reduced milk production in the following lactation. Dry periods longer than 70 days may result in over-conditioned cows and an increase in metabolic disorders.

The emphasis in ration formulation for early dry cows is to maintain the condition the cow has at the time of drying off, increasing body condition only as necessary. A condition called "fat cow syndrome" occurs when a cow becomes overweight during the dry period. This may be caused by extended dry periods, or by feeding dry cows diets high in energy feeds like grain and corn silage. Excessive body condition at calving is associated with increased incidence of several metabolic disorders, including milk fever, fatty liver, ketosis and displaced abomasum.

Current recommendations call for early dry cow diets to contain about 12% protein and .57 Mcal NE_L per pound of diet. These nutrient requirements may often be met with good quality forages alone. Many farmers include long-stem, dry hay in the diet, preferring grass hay to alfalfa hay. Alfalfa contains a great deal of calcium, and may increase the higher incidence of milk fever. Selenium may need to be added to the diet in areas where it is deficient in the soil (and therefore deficient in the forage). Recent research indicates that adding vitamins A, D, and E to dry cow diets may reduce the incidence of retained placenta and/or mastitis following calving.

Group Five: Close-up Dry Cows

Research in the last 10-15 years has made it clear that cows in the final two to three weeks before calving have very different nutritional needs than cows earlier in the dry period. Increasingly, farmers are separating these close-up dry cows, and making changes in their diet to help the cow prepare for parturition and the initiation of lactation. During the dry period, the rumen shrinks in size, microbial populations change to emphasize digestion of forages, rumen papillae shrink, and microbial numbers decrease. If cows are asked to switch from the primarily forage diet of early dry cows directly to the high grain diet fed to early lactation cows, nutritional disorders are likely.

Another important difference between group four dry cows and these close-up dry cows in group five is feed intake. Feed intake drops, often dramatically, in the final one to two weeks prior to calving. The protein and energy content of the mostly forage early dry cow ration will be inadequate during this period. If dry cows are fed throughout the dry period diets containing the energy that the close-up cows need, most cows will gain too much weight prior to calving. Finally, many farmers are using anionic salts prior to calving to prevent milk fever, and these should not be fed throughout the entire dry period.

For all of these reasons, a separate diet is recommended for cows between two and three weeks prior to calving. Compared to diets fed during most of the dry period, close-up dry cow diets will be higher in protein (14-15%), higher in energy (.74 Mcal NE_L per pound of feed), and higher in grain (.5 to 1% of body weight). The increased grain content of the diet allows the rumen microorganisms to adapt to the diets that will be fed after calving. These higher grain diets may also increase ruminal VFA production, which stimulates growth of the papillae, improving the cow's ability to absorb acids after calving. In addition to containing increased grain, diets for close-up dry cows may also contain anionic salts if this approach is used to minimize milk fever. Many farmers will continue to include good quality dry grass hay in the ration to enhance palatability and rumen fermentation.

Other Grouping Considerations

Although not included in our example grouping strategy, many farmers group and feed first calf heifers (**primiparous** cows) separately from **multiparous** cows (cows in their second or greater lactation). Nutrient requirements of primiparous cows are higher than older cows at the same level of milk yield, as first calf heifers are still growing. Likewise, bred heifers have higher nutrient requirements during the last two months of pregnancy than do older cows. Current recommendations call for bred heifers in the last two months of gestation to receive diets similar in energy and protein density to close-up dry cows (i.e., 15% protein and .74 Mcal NE_L per pound of feed).

While the grouping strategy discussed above focused on specific weeks of lactation, in practice, most farmers move cows between groups based on a variety of factors. A cow may be moved to the next group when she drops below a certain level of milk yield, when she reaches a specific body condition score, when she's checked pregnant, or simply when the pen she's in has gotten too full.

Finally, although grouping cows allows formulation of diets to more precisely meet the nutrient needs of cows, not all farmers use group feeding strategies. On many farms, all milking cows are fed the same diet because of facilities limitations or to simplify feeding management.

Practical Aspects of Feeding Forages and Cereal Grains

Forage Analysis

Routine analysis of all forages is critical to allow proper ration formulation. The protein, energy, fiber, and mineral content of forages can change dramatically as you move through the silo or feed out a barn full of hay. On most farms, hay crop silages of different cuttings, fields, and maturities are mixed in the same silo, as are corn silages from different fields. Undetected variation in the nutrient content of the forage can wreak havoc on the best-planned ration, as forages typically make up 40 to 60% of the total diet dry matter.

Good managers sample forages at harvest, and again every 1 to 3 months to monitor changes in nutrient composition. Every effort should be made to obtain a representative sample, and that sample should then be sent to a reputable laboratory for analysis.

Frequent analysis of the dry matter content of ensiled forages is as important as regular analysis of the nutrient composition. The dry matter content of an alfalfa silage, for instance, can easily change from 55% to 40% within a week when you start feeding material from a new field or cutting. Undetected changes in silage moisture content can cause you to shortchange the cow on forage and dramatically changing the ration without intending to.

Let's say, for instance, that your ration calls for 11 pounds of alfalfa silage per cow per day on a dry matter basis. If you're assuming that the silage is 55% dry matter, you'll add 20 pounds of wet silage per cow to the mixing wagon. If that silage dry matter changes to 40%, though, the 20 pounds per cow of wet silage you're feeding is actually only providing 8 pounds of dry matter! This can cause real problems for your herd, as you'll suddenly be feeding a diet much higher in grain, and lower in forage and fiber than you intended. To avoid this problem, good managers monitor the dry matter content of their forages on at least a weekly basis, using one of several on-farm methods.

Forage Quality

Regular forage analysis will keep you up to date on the dry matter, protein, and fiber content of your forages, but there are factors other than these three commonly measured nutrients that affect forage quality and cow performance. Dairy producers have long observed that some varieties of corn or alfalfa make better quality silage than others, and recent research is proving them right - corn silage isn't just corn silage any more.

Exciting research in the last decade has identified corn silage hybrids and alfalfa varieties with fiber that is more highly digestible in ruminants, and real nutritional advantages to these hybrids have been documented. While we have long known that environmental and management factors affect fiber digestibility, it is only relatively recently that repeatable, meaningful differences with corn hybrid genetics have been documented.

Increased fiber digestibility increases the energy available from the feed. Research with lactating cows indicates that fiber digestibility is potentially the single most important trait determining forage quality. Fiber is 25-35% of most dairy rations, and is the least digestible part of the diet. Because fiber is such a large (and required) part of ruminant rations, small changes in fiber digestibility make a big difference to the animal.

Most work evaluating the effect of fiber digestibility on ruminant performance has been done with **brown midrib** corn silage. Brown midrib corn is a mutant with decreased lignin content, and increased fiber digestibility as compared to normal corn. In several studies, this more digestible brown midrib mutant supported greater DMI and greater milk yield in lactating cows.

While brown midrib varieties are one way to improve fiber digestibility and forage quality, there are other ways to do so. There are normal (non-brown midrib) varieties of corn that are higher in digestibility than others. Management is also important. Harvesting forage at the appropriate maturity (not letting it get over-mature) will improve fiber digestibility. Packing bunker silos tightly and covering the silage in the bunk will dramatically improve the quality of the forage you feed your cows. Removing at least 6 inches of silage from the "face" or front of the silo each day, and keeping that "face" even will reduce spoilage, improving forage quality.

High quality forages are valuable. They can reduce feed costs by allowing the farmer to remove grain from the ration, and they can support higher feed intake and milk yield. Providing your cows with high quality forages is a process that includes planting the right varieties, harvesting and storing them appropriately, and analyzing them regularly.

Grain Feeding

Typically, diets consumed by high producing dairy cows in the United States contain high levels of starchy grains. Starch is fermented in the rumen to VFA (acetate, propionate, and butyrate) which are then absorbed and serve as the main sources of energy for the cow. Additionally, propionate is the primary precursor for synthesis of glucose by the liver. The amount of organic matter, particularly starch, fermented in the rumen is commonly viewed as the driver of microbial protein synthesis. Understanding starch digestion is the key to optimizing protein and energy supply to the cow, and to improving the efficiency and effectiveness of high grain diets.

Rumen fermentation varies with type of grain as well as conservation or processing method, and this variation can greatly affect animal performance. The starch in similarly processed wheat, oats, and barley is generally more ruminally digestible than starch in corn. Sorghum starch digestibility is the lowest of the commonly used grains.

Within a grain type, physical processing increases rate of rumen starch digestion by breaking the outer coat of the kernel to increase access of rumen microorganisms and enzymes. The application of heat, moisture, and pressure (as in high moisture or steam-flaked or steam-rolled grains) also increases rumen digestibility.

The effect of level of grain feeding and digestibility of that grain on performance of lactating cows varies. Feeding more grain, or feeding grains with higher ruminal starch digestibility (high moisture, steam-flaked, or finely ground grains) generally provides the cow with more energy, but also increases concerns about the health and productivity of animals fed these diets. Too much fermentation of starch to VFA in the rumen may overwhelm the buffering and absorptive capacity of the rumen, leading to reductions in rumen pH. This condition is known as **acidosis**, and can cause decreased DMI and/or decreased milk fat concentration. Refer to the Nutritional Disorders section for more details.

The effect of feeding more grain, or increasing rumen starch digestion on milk yield varies. Increased milk yield is often observed with increased grain feeding or increased ruminal degradation of starch , but if too rapid ruminal starch digestion causes acidosis, milk yield may decrease. Increasing the energy content of the diet by adding more grain generally increases milk protein concentration.

As genetic improvement continues in dairy cattle, nutrition must improve to meet the cow's increased need for energy and protein. Improved understanding of starch digestion allows optimization of protein and energy supply to the cow, and helps to identify management techniques to maximize the benefits of high grain diets.

Dairy calves and heifers undergo tremendous changes from the time they are born until the time they calve and enter the milking herd. They must be properly fed and managed to produce to their inherited potential after calving.

From Birth to Weaning

Newborn Calves

A newborn calf is born with a very immature immune system that cannot produce the **antibodies** a calf needs to protect it from disease and infection. Calves can get these essential antibodies through **colostrum**, the first milk produced by a cow after calving. Newborn calves must receive this colostrum shortly after birth, because within 12 hours, the calf's ability to absorb antibodies decreases significantly. It is recommended that a calf be given 3-4 quarts of colostrum within one hour after birth.

If the calf does not drink, colostrum should be given from an esophageal feeder. An **esophageal feeder** is a bag with a long tube that is put down the esophagus. The colostrum in the bag drains through the tube and goes directly into the stomach. Colostrum fed through an esophageal feeder is likely to end up in the rumen rather than in the abomasum, because the calf is not sucking, so the esophageal groove does not close. Colostrum delivered to the rumen takes a little longer to get absorbed, so it is preferable to get the calf to drink colostrum from a bottle. On the other hand, the esophageal feeder does guarantee that the calf received the colostrum, and is the best way to feed calves that simply won't drink.

In addition to providing antibodies, colostrum may provide a variety of growth factors and hormones needed for growth and development of the digestive tract. There is currently no commercial product available that can replace good quality colostrum, although some may be useful to supplement poor quality colostrum.

The antibody content of colostrum varies significantly. In general, older cows have higher quality colostrum because they have been exposed to more pathogens than have younger cows, and have developed immunity to a greater variety of diseases. The antibody content of colostrum should be measured by a **colostrometer** to ensure the calf is getting the best quality colostrum possible.

Extra, high-quality colostrum can be stored frozen for more than a year, then thawed and fed to calves whose dam's colostrum is of poor quality. Frozen colostrum should be thawed in warm water, or slowly in a microwave oven, rather than in boiling water. The extra attention required to ensure that all calves receive 3-4 quarts of high quality colostrum within one hour of birth will be paid off with healthier, growthier calves.

Milk and Milk Replacers

The stomach of a young calf is very different from that of a mature cow in that the rumen and reticulum are not well developed in a calf. During this pre-ruminant stage, highly digestible liquid diets best meet the calves' needs. At the same time, dry feed is necessary for the development of the rumen and reticulum and to establish a microbial population. Early consumption of grain should be encouraged because it will allow for quicker development of the rumen, and can allow earlier **weaning**. Weaning is the term used to describe a calf's transition to a diet comprised entirely of solid feed (no milk).

Quality milk replacers are often the most economical way to feed calves. Quality of milk replacers is not always easily determined by routine laboratory analysis. Consider the reputation of the company before making a purchase. The replacer should contain at least 22% protein and 10-12% fat. The best replacers have all of the protein coming from milk sources such as dry skim milk, dried whey, dry buttermilk, etc. Milk replacers containing alternative proteins sources are now commercially available, but may not be as digestible for very young calves. Fat should come from an animal source, most commonly choice white grease, lard, or tallow.

Feeding calves the milk from cows with mastitis is somewhat controversial. Many farmers have fed mastitic milk for years as it saves the cost of milk replacer. Mastitic milk contains mastitis-causing bacteria. While these will not likely cause the calf digestive problems, feeding mastitic milk to calves housed in groups may be a factor that increases the incidence of mastitis in unfresh and first calf heifers. If calves are allowed contact with each other, they often attempt to nurse each other. Mastitis-causing bacteria in the mouth of a calf fed mastitic milk may then be transferred to the udder of other calves. To avoid this, mastitic milk should be fed only to calves housed individually. Alternatively, some farms choose to pasteurize all milk which is fed to calves. Pasteurization will help kill any harmful bacteria in the milk.

In addition to concerns about mastitis-causing bacteria, the use of milk from cows treated for mastitis also worries people because it contains antibiotics. Milk from cows treated with antibiotics should not be fed to calves destined to be sold for meat, because the antibiotics in the milk may contaminate the meat. The other concern with feeding antibiotic treated milk is that the microorganisms in the gastrointestinal tract of these calves may develop antibiotic resistance. This is a human health concern. If calf manure containing antibiotic resistant bacteria were to contaminate a well, for instance, and people drinking from that well were to get sick from these bacteria, treatment of the illness with similar antibiotics is likely to be less effective. There is growing concern with antibiotic use in livestock because of this possibility, however remote it may seem.

Milk or milk replacer is an expensive part of the diet for young calves, so early weaning reduces feed costs considerably. Milk should be fed at about 10% of body weight. Feeding more than this increases growth rate, but will also decrease the amount of dry feed consumed, delaying weaning. Feeding warm milk or milk replacer reduces the amount of energy calves have to spend to keep warm, especially in cold weather.

Grain and Water

Calves should be offered good quality grain (also called calf starter) and water free choice from the first week of life. Highly fermentable grains lead to the production of VFA in the developing rumen, and these VFA, particularly butyrate, stimulate the growth and development of the rumen. In addition to digestibility, **palatability** is an important consideration as young calves do not readily consume dry feed. Oats and molasses are common ingredients for starters because calves like the taste. Calf starters should be fed in coarsely ground, cracked, rolled or pelleted form. Calves do not like a finely ground texture.

Contrary to conventional wisdom, hay is <u>not</u> as effective as grains in stimulating rumen growth and development. Because the rumen microorganism population is still developing, they are not as able to digest the fiber in hay as they are the more digestible, non-fiber carbohydrates in grain. Hay also limits energy intake. For these reasons, current recommendations are that hay not be fed to calves until after weaning.

The availability of clean, fresh water is very important to encourage grain consumption. In the past, many

farmers have assumed that milk or milk replacer would provide all of the water calves need. Offering free choice water (warm in the winter time) increases grain intake, however, and should be considered a routine part of good calf management.

Dairy calves should be weaned when they consume 1.75-2 lb/d of good quality calf starter for at least 3 consecutive days. This usually occurs between 6 and 8 weeks of age, but earlier weaning is possible under good management.

Weaning to Three Months of Age

The time between weaning and three months of age is a stressful time for calves, because they are often being vaccinated and undergoing a variety of changes in housing, as well as undergoing a major change in diet. Good quality legume-grass or grass hay is usually introduced to the diet at this stage, and calves are often switched from calf starter to a slightly lower protein grower.

When moved from individual pens or hutches, calves should be grouped according to size so all of them have equal opportunity to consume feed. These dietary and housing changes should be made slowly. Many farmers have found that making changes one at a time rather than all at once improves growth rates. Leaving calves in individual pens for a week or two following weaning, for instance, rather than moving them immediately to group pens will reduce stress. Also, moving calves into small groups of 4 to 5 for several weeks before moving them into larger groups may make this transition easier.

Three Months to Freshening

The time from three months of age to freshening includes several very important developmental and growth stages in a dairy heifer's life. Unfortunately, this is also the time when some farmers neglect to monitor and properly manage their young stock. Improper care in this period can result in lower production, late maturity, and delayed freshening, each of which reduces profitability.

The goals of feeding programs for these animals are to produce heifers that will reach breeding weight at 13 to 15 months and will calve at 22 to 24 months with appropriate body condition, by feeding cost-effective diets that enhance the heifer's future productive ability. After three months of age, calves and heifers are able to use hay, pasture, or silage as a primary source of nutrients. The better the quality of forages and/or pastures fed to growing animals, the less grain will be needed to meet their nutrient needs.

Figure 5 shows the target height and weight for Holstein heifers from weaning to calving. Growth curves for the other breeds are located in the Appendix. This data is based on surveys by Penn State scientists. Good managers monitor the height, weight, and body condition score of their heifers to be sure they are meeting these targets.

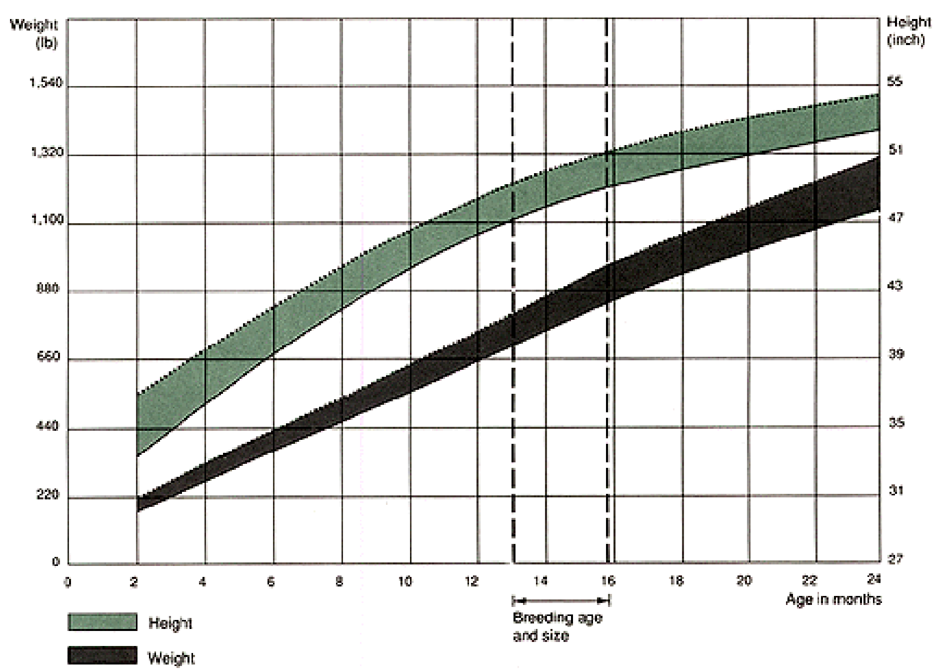


Figure 5. Target Height and Weight for Holstein Heifers from Weaning to Calving

It is important to realize that heifers reach puberty at a specific size, rather than a certain age. Dairy heifers are typically ready to be bred at about 55% of their mature body weight (450-500 lbs for Jersey heifers, 750 lbs for Holsteins). Because puberty is associated with a specific body weight rather than a specific age, inadequate nutrition can extend the time to first breeding, delaying the heifer's entry into the milking herd. Likewise, heifers that are too small at calving will often not milk as well in the first lactation, and may have reduced conception rates during that lactation as well.

On the other hand, overfeeding heifers can also decrease eventual milk production. If heifers are fed diets too high in energy, especially before puberty, the developing mammary gland will contain more fat and less secretory tissue. Diets should be formulated for growth rates that will result in Holstein heifers weighing 750 pounds at 13 months, and 1200-1250 pounds after calving.

Nutritional Disorders

Improper nutrition and nutrient deficiencies can cause many health complications in dairy cattle. Some disorders are minor and are easy to cure, but others will quickly lead to death if unnoticed or untreated. Nutritional disorders are most common in the period just before and immediately following calving.

Displaced Abomasum

A **displaced abomasum** (DA), commonly referred to as a twisted stomach, is a condition where the abomasum moves to an abnormal position in the body cavity. The abomasum will usually move to the left side of the abdominal cavity, although a right DA can occur. A right DA is considered much more serious than a left DA, because the stomach actually twists, blocking the flow of digesta. Most DAs occur in the first month of lactation.

Symptoms

- Discomfort and pain
- Reduced intake of feed and water, reduced milk yield
- Reduced volume of feces, dark colored feces
- A loud resonant ping heard over the upper right rib cage. To listen for the sound, place a stethoscope on various locations of the rib cage, and with your finger, thump the side of the stomach. A normal cow would have a deep thudding sound, while a cow with a DA will have a high, echoing "ping" sound.

Treatment

- Walking, exercise
- Rolling the cow to try to get the abomasum to return to its normal position
- Surgery to suture the abomasum to the body wall to keep it in the normal position
- Right DAs require immediate surgery to prevent irreversible damage to the abomasum

Prevention

- Dry cow diets should contain adequate fiber in both amount and particle length
- Gradually adjust cows to a higher grain ration during late dry period

Ketosis

Ketosis or acetonemia is a metabolic disorder resulting from impaired carbohydrate and VFA metabolism, leading to elevated blood ketone levels and low blood glucose. This condition usually occurs when energy need exceeds the amount of energy taken in. Ketosis is most common in high producing cows during early lactation because the cow is not taking in enough nutrients to support high production levels. Ketosis can also occur as a complication with other diseases such as metritis or retained placenta.

Symptoms

- Reduced feed intake and milk yield
- Cows appear gaunt or starved
- Cows appear depressed, dull and listless
- Rumen is inactive
- Acetone (nail polish remover) odor in breath, milk, and urine
- Weight loss
- Relatively sudden and unexplained increase in milk fat content

Cause

- Glucose needed for body maintenance is drained through milk production
- Overconditioned at calving time
- Inadequate energy intake at calving

Treatment

- Intravenous treatment (I.V.) of dextrose to increase blood sugar levels
- Oral administration of propylene glycol (**drenching**) to provide glucose precursors

Prevention

- Avoid overfeeding and overconditioning cows
- Increase grain rapidly after calving
- Avoid abrupt ration changes
- Feed good quality forages
- Some farmers routinely drench fresh cows with propylene glycol as a preventive measure

Grass Tetany

Grass tetany is a disease caused by inadequate blood magnesium levels, and is potentially fatal. It is most common in lactating animals grazing on rapidly growing, lush pastures during the beginning of pasture season.

Symptoms

- Stiff movement
- Loss of appetite
- Frequent urination

- Staggers
- Violent convulsions

Cause

- Grazing lush, spring pastures (especially wheat or rye, and especially if heavily fertilized), these usually contain low magnesium levels and high levels of potassium, potassium limits the absorption of magnesium

Treatment

- Inject magnesium sulfate or epsom salts under the skin

Prevention

- Provide adequate magnesium daily during the high risk period by feeding magnesium oxide or other magnesium source
- Supplement lush grass pasture with legumes (i.e., alfalfa) which contain more magnesium

Hardware Disease

Hardware disease is a condition which occurs when an animal swallows foreign material, usually metal. Problems occur when the object lodges itself in the reticulum or punctures other organs near the reticulum.

Symptoms

- Loss of appetite
- Digestive problems
- Tendency to stand with front feet elevated to lessen the pressure on the inflamed or sore area

Treatment

- Serious cases may require surgery

Prevention

- Good feed bunk management to keep foreign objects out of feed
- Place magnets in the reticulum of all cows
- Place magnets in feed processing equipment

Lactic Acidosis

Lactic acidosis is a condition which results from abnormal fermentation in the rumen. Acidosis may be clinical or subclinical. Clinical acidosis is more severe, with rumen pH dropping below 5, and may happen when the cow suddenly gorges on large quantities of grain. Clinical acidosis is most common in feedlot cattle fed diets with little or no forage. Sub-clinical acidosis is more subtle, with rumen pH between 5 and 5.5, and is more common on dairy farms than is clinical acidosis. Subclinical acidosis is usually caused by rations too high in grain, or not high enough in effective fiber.

Symptoms

- Loss of appetite
- High pulse rate
- Diarrhea
- Low skin temperature
- Dehydration
- Drop in urine pH
- Low rumen pH (< 5.5 = subclinical acidosis, < 5 = clinical acidosis), this can be detected using **ruminocentesis**, a technique to measure the pH of rumen fluid by inserting a long needle into the rumen
- Hooves become tender and grow abnormally (**laminitis**)

Treatment

- Force feed buffers
- Feed only forage for several days, with only gradual reintroduction of grain
- Remove all contents from rumen surgically

Prevention

- Include appropriate levels of fiber with adequate particle size in the ration
- Adjust cows to high grain diet by gradually increasing grain and by adding grain to dry cow rations before calving
- Feeding buffers to help maintain rumen pH during a diet change or when feeding high grain diets

Milk Fever

Milk fever, also known as parturient paresis, is a metabolic disorder which generally occurs in more mature cows within 48 hours after calving. Cows with milk fever have low blood calcium and little muscle strength, because lack of calcium reduces the ability of muscles to contract. When a cow calves and begins to secrete milk, large amounts of calcium are suddenly needed. The cow must be able to get calcium from the reserves in her bones to meet the needs for milk production immediately after calving. Older animals and Jerseys are more susceptible to milk fever because they generally are less able to draw from those bone reserves.

Symptoms

- Hind limb stiffness, partial paralysis, unable to rise
- Poor appetite

- Dry muzzle
- Reduced rumen movement
- Slow respiration
- Low body temperature and cold ears
- Weak heart rate

Treatment

- Give calcium salts intravenously (I.V.)

Prevention

- Avoid excessive calcium intake during the dry period. Low dietary calcium in the dry period will condition the cow to draw on the calcium stored in bone to meet her needs.
- Supplement large quantities of vitamin D for 3 days before calving, as vitamin D helps the body use calcium efficiently. Toxicity is a danger if these large quantities are fed for more than 7 days, however.
- Feed a diet with a negative dietary cation-anion balance to close-up dry cows. Feeding these diets enhances the cow's ability to draw on her bone calcium reserves, and may enhance calcium absorption. These diets are typically formulated by limiting high potassium forages and adding magnesium sulfate or other anionic salts.

Mycotoxins

Mycotoxins are toxins secreted by molds which develop on feeds. Some mycotoxins are more of a problem in drought years (i.e., aflatoxin) but others are more common in wet years (vomitoxin). If a mycotoxin problem is suspected, it's often more productive to treat the problem by adding feed additives or removing the contaminated feed rather than to test the feed for molds. It is possible for a feed to be contaminated with mycotoxins yet test negative for molds. This is because mycotoxins can persist in feeds long after the mold has died.

Symptoms

- Poor performance
- Abortion
- Liver damage
- Bloody scours
- Lameness
- Renal damage
- Hemorrhaging

Treatment

- Remove the source of the mold
- Add sodium bentonite or other feed additives that bind mycotoxins
- Inject animal with vitamin B and iron therapy

Prevention

- Proper harvesting, drying and storage of feeds
- Mold inhibitors can be added to high moisture grains

Nitrate Poisoning

Nitrate poisoning occurs when excess nitrates in the feed and water are converted to nitrites in the rumen. This nitrite is absorbed, and interacts with hemoglobin in the blood, reducing its ability to carry oxygen to the tissues. This is a dangerous condition for ruminants because the microorganisms in the rumen convert nitrates to nitrites. Drought conditions cause excess nitrate levels in forages, and high nitrates are more common in freshly cut forages (green-chop) than in silages, because silage fermentation reduces nitrates.

Symptoms

- Accelerated respiration and pulse
- Diarrhea
- Frequent urination
- Depressed appetite
- General weakness
- Trembling, staggering
- Frothing at the mouth
- Dark blood

Treatment

- Generally, death occurs too suddenly for treatment to be administered

Prevention

- Silage fermentation reduces the amount of nitrates in feed
- Including high energy feeds (i.e., grain) in the ration reduces the danger of nitrate toxicity
- Mix high nitrate feeds with other feeds
- Analyze feeds and water which are susceptible to high nitrate levels

Bloat

Bloat, sometimes known as ruminal tympany, occurs when there is an excessive accumulation of gas in the rumen. A bloated animal can not eructate or belch out the gases. If bloat is not treated it can be fatal, as rumen pressure caused by the accumulated gasses will interfere with the heart.

Symptoms

- Stomach wall protrudes (sticks out) in the area between the ribs and hip bone. Normally, this area would be slightly sunken in. In a bloated animal, this area will feel like a balloon when pressed.

Treatment

- Insert a long tube through the mouth into the rumen to allow the gases to leave the rumen through the hose
- Drench or force feed mineral oil or other anti-foaming agent to eliminate any froth or foam which may be preventing gases from escaping

Prevention

- Gradual adaptation to diet
- Feed dry hay before pasturing animals
- Feed preventative materials routinely to animals grazing legumes, such as mineral oil or bloat guard

Useful References

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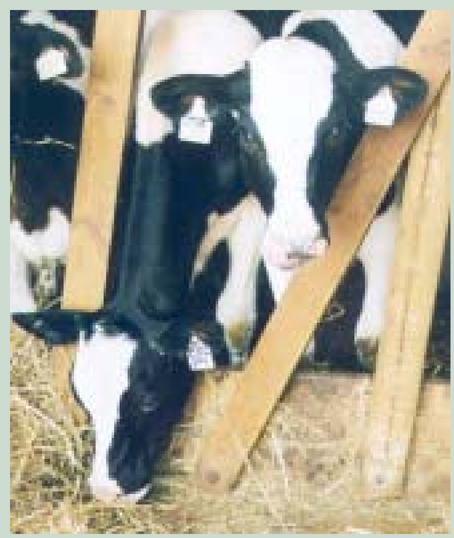


Appendix

Vitamin and Mineral Tables

Table 1. The Functions and Deficiency Symptoms of Water-soluble Vitamins

Vitamin	Functions	Deficiency Signs	Special Considerations
Thiamin	Involved in the normal functions of the central nervous system and energy metabolism	Muscular incoordination, progressive blindness	Normally synthesized by rumen microbes in sufficient quantities
Riboflavin	Assists enzymes involved in metabolism	Loss of hair, excess salivation	Normally synthesized by rumen microbes in sufficient quantities
Niacin	Assists enzymes involved in the transfer of electrons. Pre-weaned calves require supplementation.	Reduced growth and appetite	Sometimes used to prevent ketosis, but research does not support its routine use
Pyridoxine	Assists enzymes involved in protein and nitrogen metabolism	Anorexia, decreased growth convulsions	
Pantothenic Acid	Assists enzymes in energy and amino acid metabolism	Rough hair coat, dermatitis around eyes and muzzle	Normally synthesized by rumen microbes in sufficient quantities
Biotin	Assists enzymes involved in the transfer of carbon dioxide	Paralysis of the hindquarters in calves	Normally synthesized by rumen microbes in sufficient quantities
Folacin (a.k.a. Folic acid)	Part of co-enzymes in various metabolic pathways	Low white blood cell count pneumonia, death	Pre-ruminant calves may be most susceptible to deficiency
B_{12}	Needed in the synthesis of methionine and glucose	Poor general condition	Normally synthesized by rumen microbes if diet contains sufficient cobalt
Choline	Involved in fat metabolism	Fatty liver, weakness, inability to stand	Some studies indicate that feeding protected choline may increase milk yield
Vitamin C	Antioxidant	Not commonly observed	Synthesized in the body of ruminants older than 3 weeks

Table 2. The Functions and Deficiency Symptoms of Fat-soluble Vitamins

Vitamin	Functions	Deficiency Signs	Toxicity Signs	Special Considerations
A	Normal night vision, bone growth, reproduction	Night blindness, retained placentas, still births	Anorexia, scaly dermatitis, hair loss	Degrades with exposure to sunlight and heat
D	Enhances absorption of Ca and P and mobilization of these from bone	Rickets in young animals, softening of bones in older animals	Reduced DMI and milk yield, dry feces	Sunlight provides adequate amounts to animals
E	Antioxidant, immunity, reproduction	Reproductive failure, white muscle disease	Rare	Similar functions to the mineral selenium. Supplemental vitamin E may reduce mastitis.
K	Required for normal blood clotting	Delayed clotting time of blood, hemorrhaging	Non toxic	Rumen microbes synthesize adequate amounts

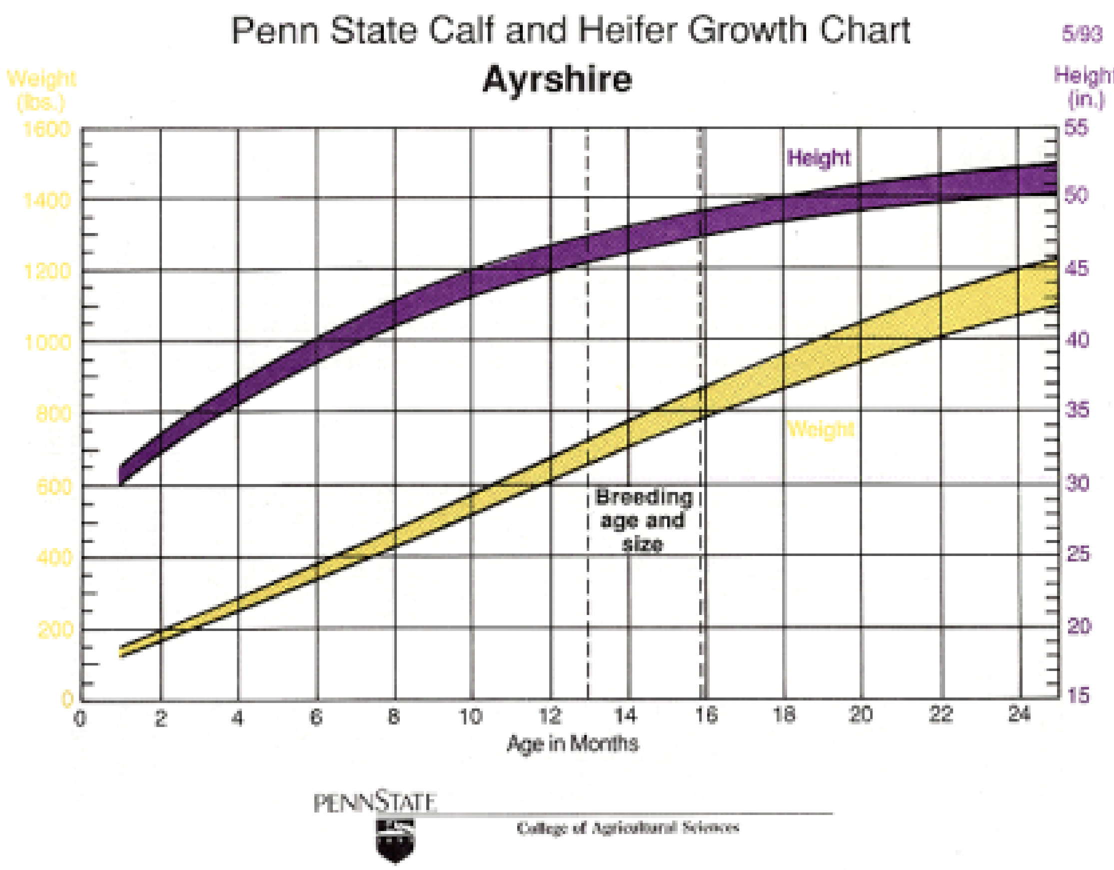
Table 3. The Functions and Deficiency Symptoms of Macrominerals

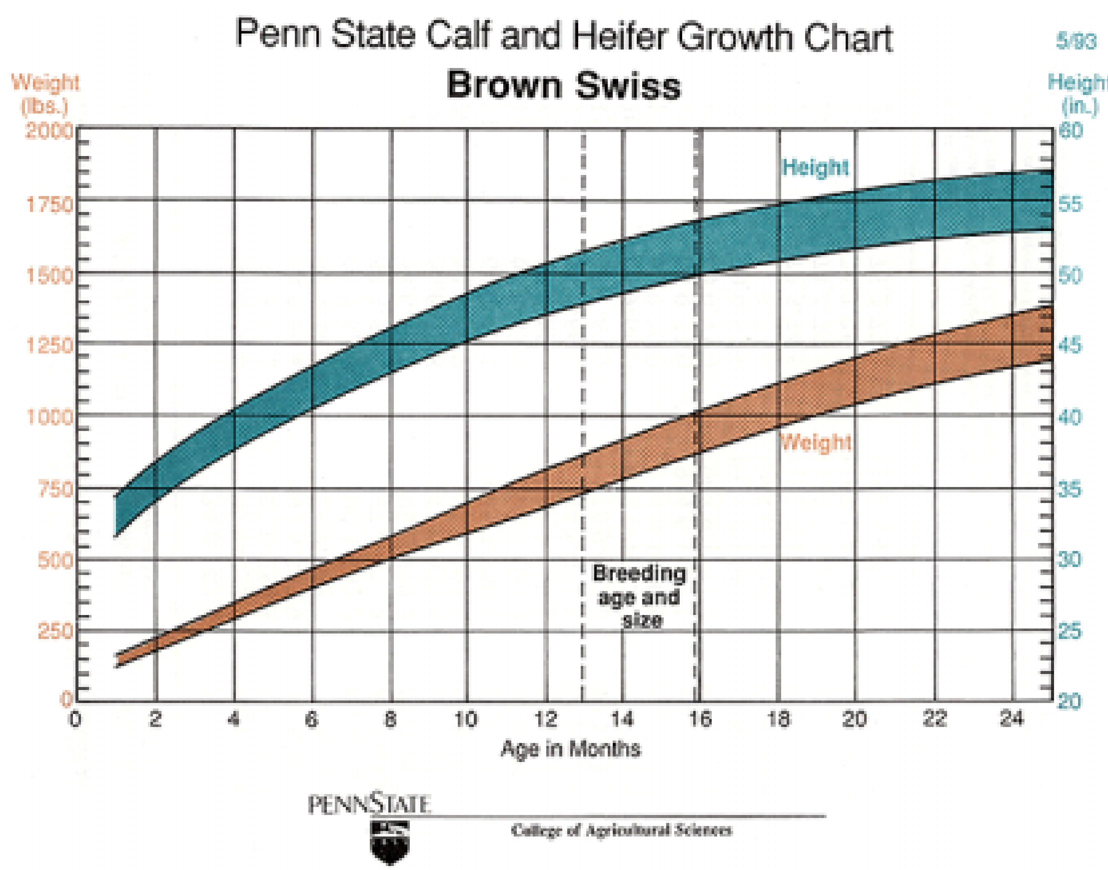
Mineral	Functions	Deficiency Signs	Toxicity Signs	Special Considerations
Calcium	Part of bones, controls nerve muscle and function, component of milk	Rickets in young animals, osteoporosis in older animals, milk fever	Abnormal thickening of skeleton, calcification of soft tissue	Older cows and Jerseys are less able to absorb Ca and mobilize it from bone, making them more prone to milk fever
Phosphorus	Part of bones, needed for energy metabolism, buffering systems, component of milk, and by ruminal microbes for fiber digestion	Rickets, depressed DMI and milk yield, impaired fertility, chewing on wood, rocks. Deficiency very uncommon with modern feed ingredients	Lameness, bone fractures, mild diarrhea	Overfeeding increases P excretion, making it more difficult for farmers to meet environmental regulations
Sodium	Transmission of nerve impulses, regulation of body water balance	Poor performance, licking and chewing objects, rough hair coat	Generally non toxic, but may increase incidence and severity of udder edema	Sodium is the only mineral animals can regulate consumption of to meet requirements
Chlorine	Found in gastric juices, important in regulation of body water balance	Blood alkalosis, reduced DMI and growth	Acidosis	
Potassium	Body water balance, muscle contraction, O_2 and CO_2 transport	Lower DMI, water intake, and milk production, licking and chewing objects	Generally non toxic, but can cause grass tetany because it interferes with magnesium utilization	Overfeeding increases manure potassium (K) content, increasing the K content of forages
Magnesium	Nerve function, muscle contraction, part of bone and some enzymes	Anorexia, excitability, calcification of soft tissue	Uncommon, occasional diarrhea, reduced feed intake	Animals unable to utilize Mg body reserves
Sulfur	Component of some amino acids and vitamins, needed by ruminal microbes	Reduced microbial protein synthesis	Excess sulfur interferes with the absorption of copper and selenium	Sulfur containing anionic salts are often added to diets of pre-fresh cows to prevent milk fever

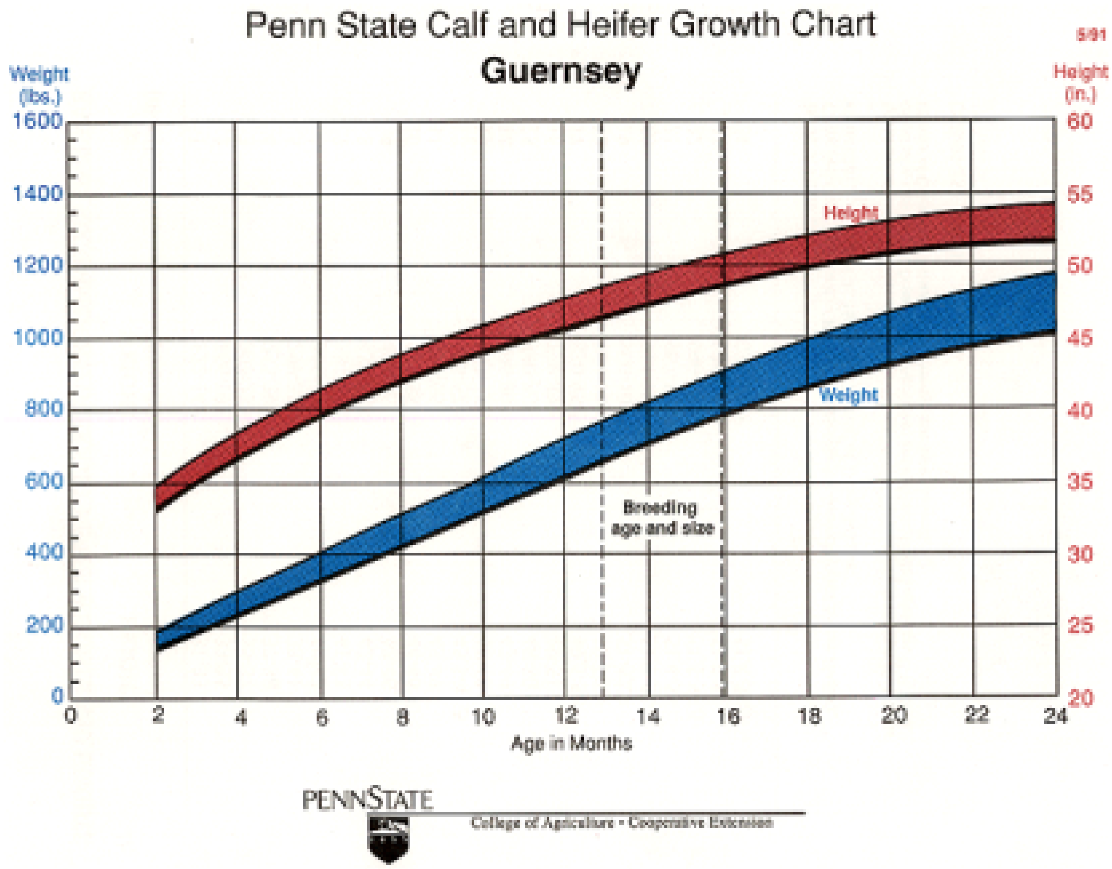
Table 4. The Functions and Deficiency Symptoms of Microminerals

Mineral	Functions	Deficiency Signs	Toxicity Signs	Special Considerations
Cobalt	Constituent of vitamin B_{12}	Poor appetite, muscular weakness	Reduced feed intake, weight loss, anemia	Deficiency signs are similar to signs of toxicity
Iodine	Associated with the rate of metabolism	Goiter, reduced fertility	Tears, excess saliva, respiratory problems	FDA regulates iodine supplementation
Iron	Component of hemoglobin, enzymes, and cytochrome	Anemia - rare, because many soils are high in iron	Diarrhea, reduced growth, impaired absorption of other minerals	Cow's milk is low in iron
Copper	Iron metabolism, connective tissue formation, respiration	Reduced growth, changes in hair color and texture, scours, anemia	Jaundice, hemoglobin in urine, death	The most likely of all minerals to cause toxicity-Jerseys are more susceptible to copper toxicity than Holsteins
Zinc	Part of many enzymes	Reduced growth and DMI, dermatitis	Interferes with copper absorption	
Manganese	Bone formation, activates many enzymes	Skeletal abnormalities, silent heats	Uncommon	
Selenium	Antioxidant, required for pancreatic function	White Muscle Disease, low fertility, retained placenta	Blind staggers, lameness, hoof deformities	Works with Vitamin E - FDA regulates selenium supplementation

Growth Charts for Heifers






Penn State Calf and Heifer Growth Chart
Guernsey
5/91
Weight (lbs.)
Height (in.)
1600
1400
1200
1000
800
600
400
200
0
60
55
50
45
40
35
30
25
20
Height
Weight
Breeding age and size
0
2
4
6
8
10
12
14
16
18
20
22
24
Age in Months
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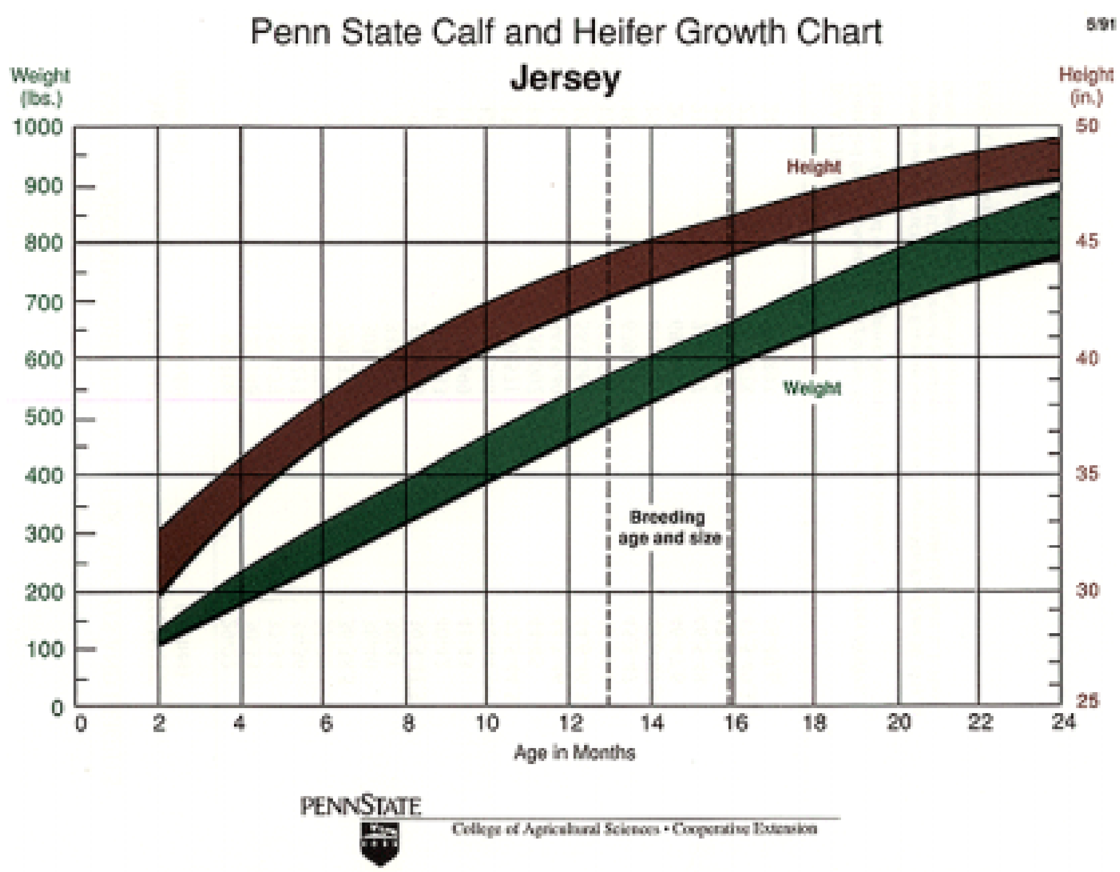
Penn State Calf and Heifer Growth Chart
Jersey
5/91
Weight (lbs.)
Height (in.)
1000
900
800
700
600
500
400
300
200
100
0
50
45
40
35
30
25
Height
Weight
Breeding age and size
0
2
4
6
8
10
12
14
16
18
20
22
24
Age in Months
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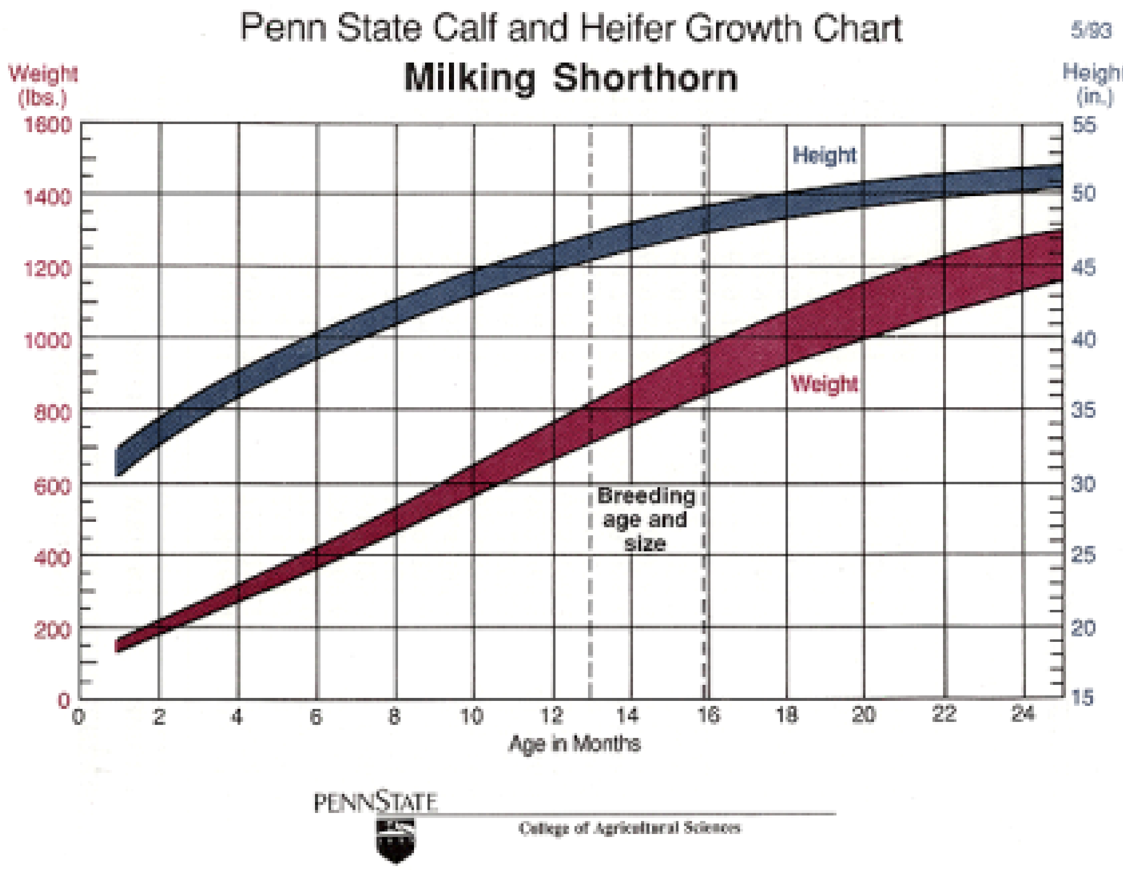

Penn State Calf and Heifer Growth Chart
5/93
Milking Shorthorn
Weight (lbs.)
Height (in.)
1600
1400
1200
1000
800
600
400
200
0
55
50
45
40
35
30
25
20
15
Height
Weight
Breeding age and size
0
2
4
6
8
10
12
14
16
18
20
22
24
Age in Months
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Glossary

Abomasum	The fourth compartment of the ruminant stomach. The abomasum functions much like the human stomach, and is the largest and most important compartment in the young calf.
Acid Detergent Fiber (ADF)	A measure of the amount of cellulose and lignin in a feedstuff.
Acidic	Having a pH below 7.
Alkaline	Having a pH above 7.
Amino Acids	The basic building blocks of proteins.
Anaerobic	Living or functioning without oxygen present.
Antibiotic	Compound which has an inhibitory or detrimental effect on organisms.
Antibodies	A special protein released by the body that recognizes and destroys foreign cells or microorganisms in blood.
Asphyxia	A lack of oxygen, common when eating or choking.
Bile	A secretion from the liver that contains cholesterol and bile salts which aid in the digestion and absorption of fats.
Bloat	A condition when an animal can not eructate (belch), which causes gases to build up in the stomach.
Bolus	A solid mass of feedstuff which a ruminant regurgitates back up to remasticate or chew during rumination.
Brown Midrib Mutant	A type of corn with decreased lignin content and higher fiber digestibility than normal corn.
Buffer	A compound which resists changes in pH or hydrogen ion concentration.
Carbohydrate	Nutrient found in many different plant tissues which contains carbon, hydrogen and oxygen and is the main energy storage compound in plants.
Cecum	A blind pouch located at the junction of the small intestine and the large intestine.
Cellulase	The enzyme which works to degrade (break up) cellulose. It is secreted by some microorganisms, but not by mammals.
Cellulose	A complex carbohydrate (polysaccharide) found in plant tissue which helps support the plant against bending. Cellulose is indigestible to mammals unless microorganisms possessing cellulase are present in the digestive tract.
Chyme	A term used to describe the partially digested material found in the small and large intestines.
Colon	Another word for the large intestine.
Colostrometer	A device used to measure the concentration of antibodies in colostrum.
Colostrum	The first milk produced by a cow after calving. It is high in energy and antibodies.
Digesta	A term used to describe the partially digested material found in the small and large intestines.
Digestible Energy (DE)	The total energy in the feedstuff minus the energy lost in feces.

Glossary

Disaccharide	A compound formed by the linkage of two monosaccharides (simple sugars). Lactose is the disaccharide formed by the linkage of glucose and galactose.
Displaced Abomasum	A condition where the abomasum moves into abnormal positions inside the body cavity, causing severe digestive problems.
Drench	The process of force feeding an animal. Drenching is commonly used to treat for digestive problems.
Dry Matter (DM)	The portion of a feed that remains after water has been removed by drying. All of the nutrients in a feed are located in the DM portion.
Duodenum	The upper segment of the small intestine where secretions enter from the pancreas and liver.
Energy Balance	The amount of energy taken into the body relative to the amount of energy required by the body. Cows in positive energy balance gain weight, while those in negative energy balance lose weight.
Enzyme	A protein which acts as a catalyst in starting or speeding up specific chemical reactions.
Eructation	Belching of gas by ruminant animals as a natural way for releasing gases produced during the fermentation process.
Esophageal Groove	A muscular structure in the lower end of the esophagus, which, when closed, forms a tube from the esophagus to the omasum. It allows milk consumed by young ruminants to bypass the undeveloped rumen and reticulum.
Fat (Lipids)	High energy nutrients made up of triglycerides and fatty acids.
Fatty Acids	The basic building blocks of fats.
Feedstuff	Any substance suitable for animal feed; several feedstuffs are combined to make a balanced diet.
Fermentation	Chemical changes produced in a substance brought about by microorganisms.
Gluconeogenesis	The synthesis of glucose in the liver from propionate, lactate, or other absorbed compounds.
Gross Energy (GE)	The total energy found in food. Often referred to as Intake Energy (IE).
Hardware disease	A condition which occurs when foreign material such as metal is ingested by a bovine. This metal causes cuts or punctures in the lining of the reticulum and the abdominal cavity.
Hemicellulose	A complex carbohydrate (polysaccharide) found in plant tissue which helps support the plant against bending. Cellulose is indigestible to mammals unless microorganisms possessing fiber digesting enzymes are present in the digestive tract.
Hormone	A substance secreted into the blood in small amounts that act on tissues in other parts of the body to produce a biological response.
Ileum	The lower segment of the small intestine between the jejunum and colon.
Ingest	To eat or take in through the mouth.
Jejunum	The middle section of the small intestine between the duodenum and ileum.
Large Intestine	The part of the digestive system after the small intestine and before the rectum. It is the primary site of water absorption. It can also be referred to as the colon.

Glossary

Liver	A large organ in the body located beneath the diaphragm. It produces bile and antibodies, synthesizes glucose and urea, stores iron, copper, vitamins A and D, and removes toxic substances from the body.
Lymph	A slightly yellow fluid which flows through the lymphatic channels in the body. Absorbed fats are transported in lymph to the circulating blood.
Macrominerals	Minerals which are required by the body in relatively large quantities - greater than 1 gram per day. These include Ca, P, Na, Cl, K, Mg, and S.
Maintenance requirement	The nutrients needed just to maintain the body.
Metabolic Disorder	A condition which occurs when problems occur in any metabolic function of the body. Examples are milk fever, displaced abomasum, and ketosis.
Metabolizable Energy (ME)	Digestible energy minus energy lost through the release of gases and urine.
Microorganisms	Microscopic living organisms, including bacteria, protozoa, and fungi.
Microbial protein	Proteins formed by the microorganisms in the rumen. Microbial protein provides most of the protein needed by cows.
Microminerals	Minerals required by the body in relatively small amounts. These include Co, I, Fe, Cu, Zn, Mn, and Se.
Minerals	Inorganic substances found in nature of a definite chemical structure.
Monogastric	An animal having one chamber, simple stomach. Humans, pigs, and chickens are all monogastrics.
Monosaccharide	Simple sugars, the basic building blocks of carbohydrates. Glucose and sucrose are examples.
Multiparous	An animal that has given birth more than once.
Mycotoxins	Toxic compounds produced by molds.
Net Energy (NE)	The actual amount of energy the body can use for growth, lactation, reproduction and body maintenance. It is equal to the total energy in the feed minus energy lost in the feces, urine, gas, and heat production. Also known as Retained Energy (RE).
Neutral Detergent Fiber (NDF)	A measure of the amount of hemicellulose, cellulose, and lignin in a feedstuff.
Non-Protein Nitrogen (NPN)	Nitrogen containing compounds which are not proteins. Ammonia and urea are examples.
Omasum	The third compartment of the ruminant's stomach; is a site of water absorption.
Palatability	The taste or likability of a feedstuff.
Pancreas	An organ of the digestive tract that produces hormones (insulin and glucagon) and digestive enzymes.
Pathogen	A microorganism which causes disease.

Glossary

Pepsin	A proteolytic (protein digesting) enzyme produced by the stomach.
Peristalsis	The wavelike contractile motion which propels food and digesta through the digestive tract.
pH	The degree of acidity or alkalinity of a solution.
Polysaccharide	The complex carbohydrate formed from the linkage of three or more monosaccharides. Cellulose and starch are examples.
Primiparous	An animal that has only given birth once.
Regurgitation	The process of bringing food back up the esophagus during rumination.
Remastication	The process of chewing the food again during rumination.
Rennin	A milk-curdling enzyme that comes from the glandular layer of the stomach of a calf.
Retained Placenta (RP)	A disorder which occurs when the animal does not release the placental tissues from the uterus after calving.
Reticulum	The second compartment of the ruminant stomach, closely related with the rumen. It functions include moving ingesta with the rumen and omasum and regurgitation of the bolus during rumination.
Rumen	Largest compartment of the stomach containing billions of microorganisms capable of degrading complex carbohydrates and synthesizing amino acids and vitamins for the host animal.
Ruminally undegraded protein (RUP)	The fraction of the protein in feed that escapes rumen fermentation. This fraction is also sometimes known as undegradable intake protein (UIP) or as bypass protein.
Rumination	A process in ruminants in which partially digested feed is regurgitated, remasticated (re-chewed) and reswallowed for further digestion.
Saliva	A liquid secretion produced in the mouth which helps lubricate food and begin the digestive process.
Scours	Another name for diarrhea.
Small Intestine	The portion of the digestive system between the abomasum and the large intestine. It is the primary site of nutrient absorption.
Solvent	A substance or fluid which is capable of dissolving another substance.
Starch	A complex carbohydrate found mainly in plant seeds. Starch can be digested by enzymes secreted by mammals and microorganisms.
Total Mixed Ration	A mixture of all of the ingredients of an animal's ration.
Villi	Small thread-like projections lining the inside of the wall of the small intestine that increase the surface area for absorption of nutrients.
Vitamin	A food constituent that is essential in small amounts for the proper functioning of the body.
Volatile Fatty Acids (VFA)	Energy compounds produced by microorganisms via fermentation of carbohydrates.
Weaning	The transition of a calf from a milk-based diet to a diet comprised entirely of solid feed.

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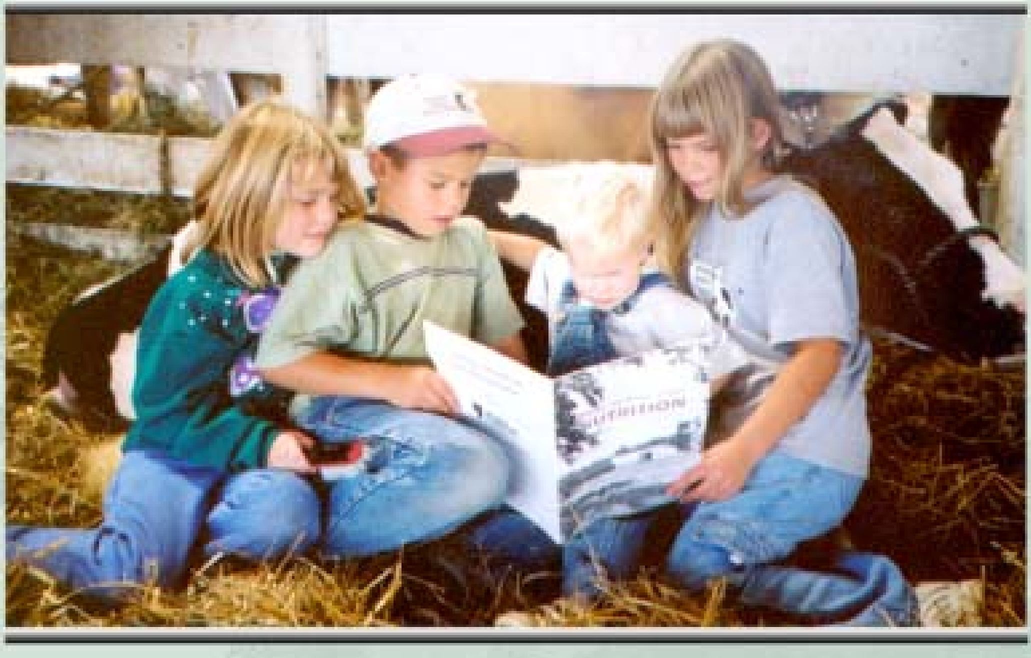

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