5

How the rumen works

This chapter:

Explains the role of the rumen, which allows breakdown and digestion of the forages consumed by cows.

The main points in this chapter:

- cows rely on rumen microbes to convert feed components into useable sources of energy and protein
- speed of digestion depends on the size of feed particles, digestibility of feed and level of intake
- growth and multiplication of microbes depends on rumen pH and the supply of energy and protein
- rumen microbes ferment carbohydrates to make Volatile Fatty Acids (VFA) and gases
- Volatile Fatty Acids are the major source of energy for the cow and the amount of each Volatile Fatty Acid produced depends on the diet
- microbes break down rumen degradable protein and non-protein nitrogen into amino acids and ammonia to build more microbial protein
- microbes are flushed out of the rumen and digested and absorbed in the abomasum and small intestine – this 'microbial protein' supplies most of the cow's protein
- dietary protein not broken down in the rumen can also be digested and absorbed in the abomasum and small intestine
- most fats are digested in the small intestine.

Unlike monogastrics, cattle have rumens, which allows them to make use of feeds that would otherwise be wasted if consumed, through the microorganisms (or microbes) living in the rumen. Therefore, the approach to feeding dairy cows is 'look after these microbes and they will look after the cow'.

5.1 The digestive system

Three steps are involved in cows obtaining nutrients from their diet:

- ingestion: taking food into the body
- digestion: food is mechanically and chemically broken down
- absorption: nutrients pass from the digestive system into the cow's blood stream.

The digestive system of dairy cows is well adapted to a forage-based diet. As ruminants, cows have one true stomach (the abomasum) and three other compartments (the rumen, the reticulum, the omasum) which each have specific roles in the breakdown of the feed consumed (Figure 5.1).

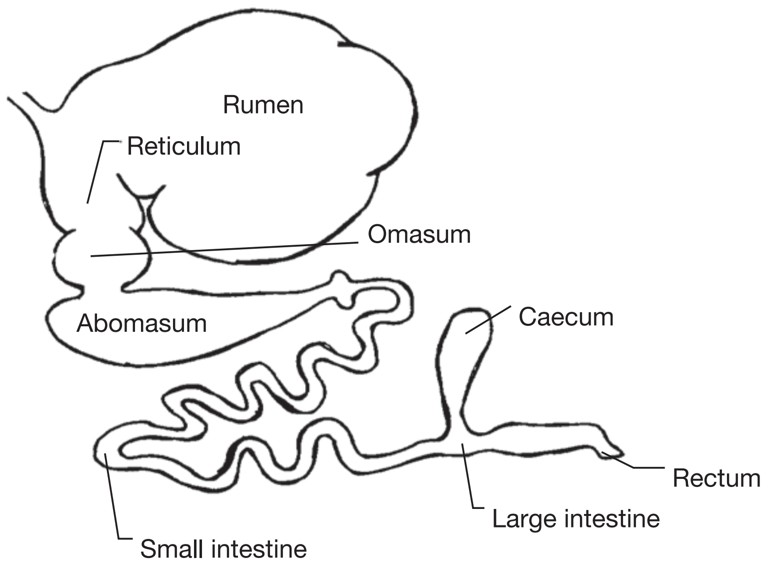

Figure 5.1 Digestive system of the dairy cow.

5.1.1 Rumen and the reticulum

Once food has been ingested, it is briefly chewed and mixed with saliva, swallowed and then moved down the oesophagus into the rumen. The rumen is adapted for the digestion of fibre. It is the largest compartment of the adult ruminant stomach. The rumen is sometimes described as a 'fermentation vat'. Its internal surface is covered with tiny projections, papillae, which increase the surface area of the rumen and allow better absorption of digested nutrients.

The reticulum is separated from the rumen by a ridge of tissue. Its lining has a raised honeycomb-like pattern, also covered with small papillae. The rumen and reticulum together have a capacity of 50 to 120 L of food and fluid. The temperature inside the rumen remains stable at around 39°C (range 38–42°C) which is suitable for the growth of a range of microbes.

The microbes break down feed through the process of fermentation. Under normal conditions, the pH of the contents of the rumen and reticulum is maintained in the range of 6 to 7. It may be lower in grain-fed cows. The stable pH range is maintained by continual removal, via the rumen wall, of acidic end products of microbial fermentation, and by the addition of bicarbonate from the saliva.

Saliva

Saliva has several roles: it makes chewing and swallowing easier, but primarily it contains sodium (Na) and potassium (K) salts that act as buffering agents against acidity.

A cow can produce 150 L or more of saliva daily. The volume of saliva secreted depends on the time spent eating and ruminating.

Chewing and rumination

Before food reaches the rumen its breakdown has already started by the mechanical action of chewing. Enzymes produced by the microbes in the rumen initiate chemical breakdown. The walls of the rumen and reticulum move continuously, churning and mixing the ingested feed with the rumen fluid and microbes. The contractions of the rumen and reticulum help the flow of finer food particles into the next chamber, the omasum.

Rumination, or chewing the cud, is the process whereby newly eaten feed is returned to the mouth for further chewing. This extra chewing breaks the feed down into smaller pieces, thereby increasing the surface area of food particles, making it more accessible to the rumen's chemicals. As a result, the rate of microbial digestion in the rumen is increased.

The time spent ruminating (chewing the cud) depends on the fibre content of the feed. The more fibre in the feed, the longer the ruminating time required, therefore the less feed that can be eaten overall, and the less milk will be produced.

Some nutrients are absorbed across the rumen wall. Absorption involves the movement of individual feed components through the wall of the digestive tract into the blood stream where they are transported to the liver.

There is a constant flow of digesta through the digestive tract. Because food larger than 1 mm cannot leave the rumen until its length is reduced, the rumen is the major regulator of feed intake.

Passage of food through the rumen

The passing of material through the rumen affects the extent of digestion. The general rate of passage depends on density, particle size, ease of digestion and level of feeding. Some foods pass through the digestive system fairly quickly, but very indigestible food may be excreted over a long period.

5.1.2 Microbes of the rumen and the reticulum

The microbes in the rumen include bacteria, protozoa and fungi. These microbes feed on forages ingested by the cow, and, by fermentation, produce end products that are utilised by the cow as well as by the microbes themselves for their own reproduction and cell growth.

Bacteria and protozoa are the most important microbes. Billions of bacteria and protozoa are found in the rumen. They digest about 70% to 80% of the digestible dry matter in the rumen. Different species of bacteria and protozoa perform different functions. Some digest starch and sugar while others digest cellulose.

The numbers and proportions of each type of microbe depend on the animal's diet. Maintaining a healthy mixture of different microbes is essential for keeping the rumen functioning efficiently.

The major end products of microbial fermentation are:

- Volatile fatty acids, the products of fermentation and the cow's main energy source.
- Ammonia, used to manufacture microbial protein. Bacteria are 60% protein, making them the major source of protein for the cow as they leave the rumen and are digested in the abomasum and small intestine.
- Gases, sources of wasted energy, as they are belched out regularly.

Dietary upsets, such as feeding too much grain too quickly, can cause a rapid change in the microbial population. This changes fermentation patterns and interferes with fibre digestion. The level of grain fed should be adjusted gradually so that the populations of rumen microbes can change accordingly.

5.1.3 Rate of digestion

The speed of digestion of feeds depends on the quality and composition of the feed. It is affected by the number and type of microbes, the pH in the rumen, the nutrients that limit the growth of the microbes and the removal of microbes from the rumen. Energy and protein are the major nutrients that limit microbial growth and, therefore, rumen fermentation.

The microbial population needs energy and protein for growth and multiplication. If either of these nutrients is in short supply, microbial growth is retarded, and so is the rate of digestion (the digestibility) of feed.

5.1.4 Omasum

The omasum lies between the reticulum and abomasum. The material entering the omasum is made up of 90% to 95% water. The primary function of the omasum is to remove some of this water and to further grind and break down feed. Large plate-like folds, known as laminae, extend from the walls of the omasum. These folds are attached in the same way as pages are bound to the spine of a book. The laminae are covered in papillae which direct the flow of food particles towards the next chamber, the abomasum.

5.1.5 Abomasum

The abomasum connects the omasum to the small intestine. Acid digestion, rather than microbial fermentation, takes place in the abomasum, much the same as in the human stomach.

The lining of the abomasum is folded into ridges, which produce gastric juices containing hydrochloric acid and enzymes (pepsins). The pH of these gastric juices varies from 1 to 1.3 making the abomasum very acid, with a pH of about 2.

The acidity in the abomasum kills the rumen microbes. The pepsins carry out the initial digestion of microbial and dietary protein in the abomasum.

Tropical dairy farming : feeding management for small holder dairy farmers in the humid tropics
By John Moran, 312 pp., Landlinks Press, 2005

5.1.6 Small intestine

From the abomasum the digested food moves to the small intestine. Secretions of bile, with a very high pH, change the digesta from acidic to alkaline, allowing digestion of different feed nutrients. There, enzymes continue the digestion of feeds and microbes. Most nutrient absorption occurs in the small intestine.

5.1.7 Large intestine

The large intestine, mainly the caecum and colon, is the site of secondary fermentation, particularly of fibre. About 10% to 15% of the energy used by the cow is absorbed from the large intestine. Absorption of water, minerals and ammonia also occurs here. The components of feed not digested in the large intestine pass through to the rectum and are then expelled as faeces.

5.2 Carbohydrate digestion in the rumen

When food is eaten by the cow, the nutrients are initially in the form of carbohydrates, proteins and fats (or lipids). These are digested to products, which can be used directly by the cow or by the microbes in the rumen.

Plant tissue dry matter is about 75% carbohydrate. Microbial fermentation breaks carbohydrates down into simple sugars. The microbes use these sugars as an energy source for their own growth and make end products, which are used by the cow.

The end products of microbial fermentation of carbohydrates include:

- volatile fatty acids, mainly acetate, propionate and butyrate
- gases, such as carbon dioxide and methane.

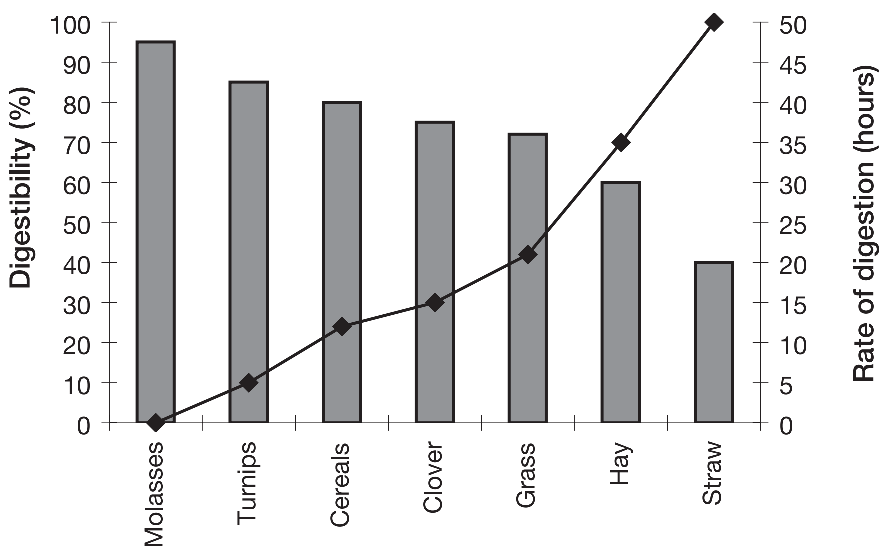

Figure 5.2 Relationship between digestibility ■ and rate of digestion ◆. (Source: Ørskov 1987)

Rumen microbes ferment all carbohydrates, but the soluble and storage forms are fermented more quickly than the structural forms. Sugars and starches are broken down easily and quickly. By comparison, cell-wall material is digested slowly.

As plants mature their cell walls become lignified. The lignin reduces the availability and utilisation of structural carbohydrates. In other words, as plants mature, their digestibility declines because the components of their cell walls become less accessible and harder to digest.

Soluble carbohydrates are digested 100 times faster by the microbes in the rumen than are storage carbohydrates, while storage carbohydrates are digested about five times faster than the structural carbohydrates.

Figure 5.2 shows the relationship between digestibility and rate of digestion for some common feeds.

5.2.1 Structural carbohydrates

Bacteria, which digest structural carbohydrates (cellulose and hemicellulose), produce a large proportion of acetic acid, important in the production of milk fat. These bacteria are sensitive to fats and acidity in the rumen. If feeds contain too much fat or if the rumen becomes too acidic through feeding rapidly digestible carbohydrates, these bacteria can be completely eliminated or their growth rate slowed down. Reduction or elimination of these bacteria not only reduces the digestibility of the feed, it may also reduce the cow's intake of feed.

Once structural carbohydrates have passed through the rumen, there is little likelihood that they will be broken down further.

5.2.2 Storage carbohydrates

The bacteria that digest starchy feeds (eg cereal grains or potatoes) are different from the cellulose-digesting bacteria. They are insensitive to acidity and produce mainly propionic acid. Starches are rapidly fermented, and the lactic and propionic acid they produce causes acidity to increase. The acidity caused by excess starch-digesting bacteria can suppress the bacteria which digest cellulose and so reduce the milk fat level.

5.2.3 Soluble sugars

The bacteria that ferment feeds high in soluble sugars (eg molasses, sugar cane, good quality grass) are similar to those that ferment starch. Sugary feeds generally cause fewer problems with increased acidity in the rumen than starchy feeds (see Section 5.2.4 below). However, sugary feeds need to be introduced to the cow's diet slowly.

5.2.4 The products of carbohydrate digestion

Volatile Fatty Acids

The most important end products of carbohydrate breakdown in the rumen are Volatile Fatty Acids (VFAs). These acids are important because:

- they are the major source (70%) of energy for the ruminant
- the proportions in which they are produced determine fat and protein content of milk.

The three major Volatile Fatty Acids produced are acetate (or acetic acid), propionate (or propionic acid) and butyrate (or butyric acid). The ratio of the various Volatile Fatty Acids produced depends on the type of feed being digested.

Volatile Fatty Acids are absorbed through the walls of the rumen and are then transported in the blood to the liver. In the liver they are converted to other sources of energy. From the liver, the energy produced is used to perform various functions (ie milk production, maintenance of body systems, pregnancy, growth) (Figure 5.3).

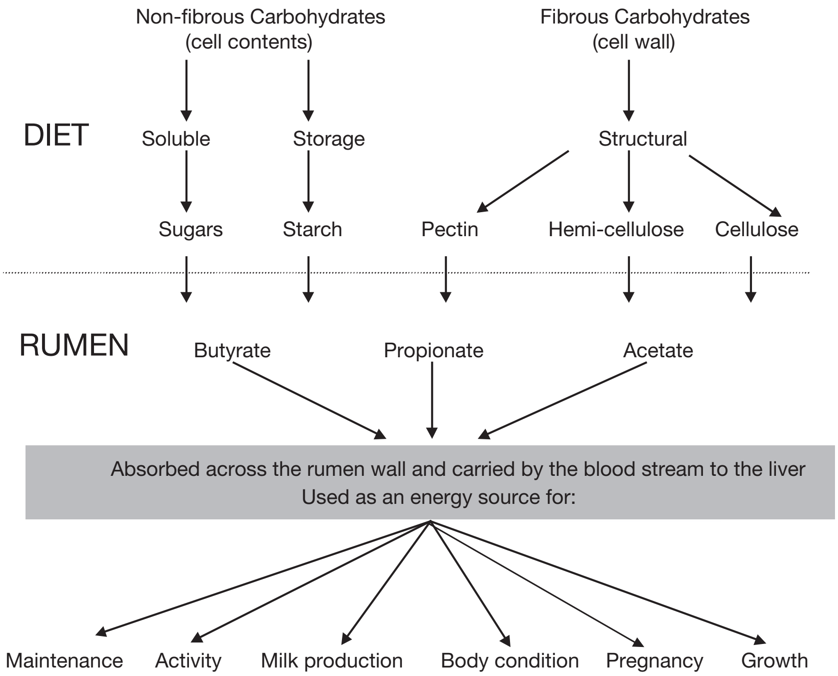

Figure 5.3 Digestion of carbohydrates, and production and absorption of volatile fatty acids in the dairy cow. (Source: Target 10 1999)

Acetate

Acetate is an end product from the fermentation of fibre. Highly fibrous, low energy feeds such as pasture hay lead to microbial populations which produce high ratios of acetate to propionate.

Acetate is necessary for the production of milk fat. If acetate production is low, which occurs in diets high in grain (or low in fibre), milk fat production may be depressed.

Propionate

Propionate is an end-product of fermentation of starch and sugars. Most of the energy needed for live weight gain and for the mammary system to produce lactose is obtained from propionate.

Feeds high in rapidly fermentable carbohydrates such as cereal grains lead to populations of bacteria which produce relatively more propionate and butyrate than acetate. Propionate is considered a more efficient energy source because fermentations, which favour the production of propionate, produce less wasted methane and carbon dioxide.

If too little propionate is produced, which can occur during the feeding of high-fibre diets, the synthesis of milk lactose and overall milk yield is reduced. To compensate for the energy deficit caused by insufficient propionate, body fat is mobilised and the cow loses body condition.

Butyrate

Butyrate is metabolised in the liver into ketone bodies. Ketone bodies are used as a source of energy for fatty acid synthesis, skeletal muscles and other body tissues. Ketone bodies are also produced from the mobilisation of body fat. If a cow is underfed in early lactation and loses body condition to compensate for a lack of dietary energy, the ketone bodies are utilised as an alternative energy source.

Further details of the roles of VFAs in dairy cow diets are discussed in Chapter 14.

Gas

Carbon dioxide and methane are produced during the fermentation of carbohydrates. They are either removed through the rumen wall or lost by eructation (belching). Some carbon dioxide is used by the intestinal microbes and by the cow to maintain bicarbonate levels in saliva. Methane cannot be used by the cow's body systems as a source of energy.

5.3 Digestion of protein

Protein, when digested, is broken down into peptides, which are short chains of amino acids. Further digestion of peptides yields individual amino acids and eventually ammonia. The protein used by the cow may be from the feed she eats or from the microbes washed from the rumen. The amount of each depends on the extent to which dietary protein is degraded in the rumen and on the growth and outflow of microbes from the rumen (Figure 5.4).

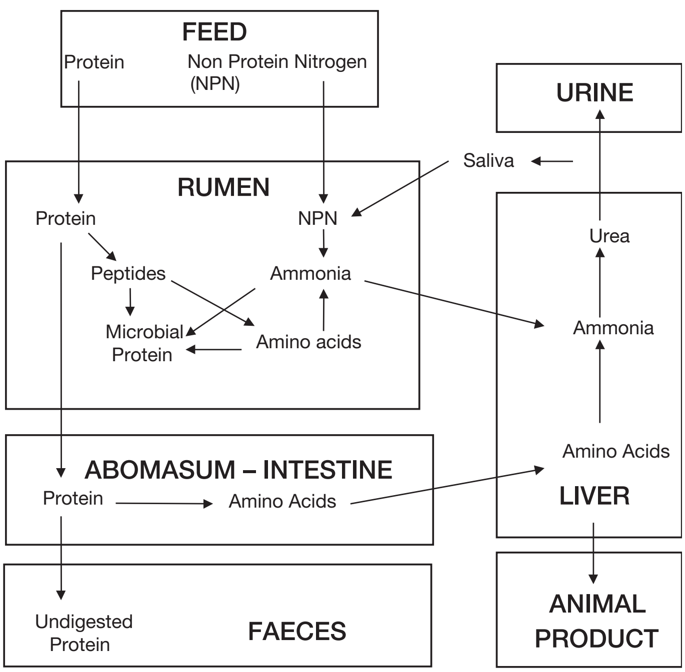

Figure 5.4 Breakdown and partitioning of dietary and microbial protein sources in the dairy cow. (Source: Target 10 1999)

5.3.1 Microbial protein

Rumen microbes are the major source of protein in the cow's diet. They break down Rumen Degradable Protein (RDP) to amino acids, then ammonia. Ammonia is a major source of nitrogen for microbial growth. The microbes also convert non-protein nitrogen to ammonia.

Microbes are continually 'flushed' from the rumen, through the omasum to the abomasum, where they are killed and digested by the cow. The amino acids produced from the digested microbial protein are absorbed through the small intestine. The amount of microbial protein flowing to the intestines depends on the availability of energy and ammonia in the cow's diet.

If energy is limited, microbes become less efficient at using ammonia. Instead of being converted to microbial protein, the ammonia is absorbed across the rumen wall and into the bloodstream. In the liver, ammonia is then converted to urea. Most of this urea is excreted in the urine although some is recycled back into the rumen as non-protein nitrogen in the saliva.

When energy is in excess relative to protein, the rate of microbial protein synthesis declines. Total protein supply to the cow is reduced and milk yield and milk protein yield decreases. Excess energy is converted to body condition rather than milk. Generally, though, good quality forage-based diets are relatively high in protein.

5.3.2 Dietary protein

The dietary protein that is directly available to the cow is Undegradable Dietary Protein (UDP) and any rumen degradable protein which has escaped microbial digestion. This protein is digested in the abomasum and small intestine. Undegradable protein and 'escape RDP' provide a greater diversity of amino acids than does protein broken down in the rumen, which is restricted to those proteins, and their component amino acids, found in microbes.

5.4 Digestion of fats

Fats are a source of energy for the cow. Fats are either partially degraded in the rumen or assume a bypass or protected form. When microbial fermentation of fats occurs in the rumen, some vitamins required by the cow are also produced. Fats are present in most of the more common dairy feeds in relatively small amounts.

No more than 5% of the total diet dry matter (or about 500 g/d) should consist of fats. Beyond this level, fat will coat the dietary fibre in the digestive tract, interfering with fibre digestion and decreasing the palatability of the diet.

Protected fats, which escape microbial digestion in the rumen, can be used to overcome the digestive upsets caused by high levels of rumen-degradable fat. The protected fats are readily digested and absorbed across the wall of the small intestine. Interest in feeding protected fats to lactating dairy cows is growing. However, they are very expensive and only relevant to high producing herds (30 L/d or more), and therefore are not practically relevant to small holder farmers.

Fats such as those from oilseeds (eg whole cottonseed) are useful because they increase the energy density of the diet, particularly in early lactation, thus helping to reduce live weight loss.